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A SUMMARY OF RPC2014

B.Satyanarayana
Department of High Energy Physics
TIFR, Mumbai

Plan of the talk

- Introduction
- Detector R&D
- Signal Readout
- Detector performance
- New deployments
- Applications
- Outlook

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XII workshop on Resistive Plate Chambers and Related Detectors (RPC2014)

February 23-28, 2014, Tsinghua University, Beijing, China

Plan of the talk

- Introduction
- Detector R&D
- Signal Readout
- Detector performance
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LEE, Kyong Sei (KODEL)

Rate-capability study for a four-gap phenolic RPC with a Cs-137 source

Detector characteristics for phenolic (HPL) 4-gap RPCs

- ✓ Rate capability ~ 5 kHz cm^{-2}
- ✓ Time resolution σ ~ 1 ns
- ✓ Detectors can be produced with the same method as the current 2-gap RPCs
- ✓ Strip layout → same as for the current 2-gap RPCs
- ✓ Oiling required to reduce noises

4-gap RPCs

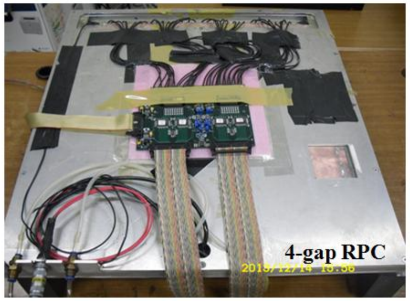
Timing RPCs ← q_e

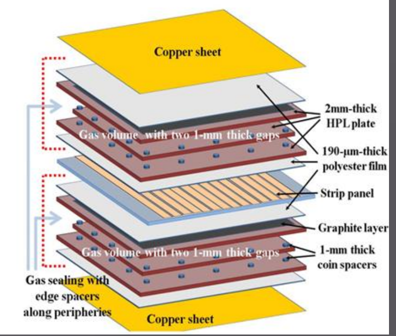
Other characteristics →
Construction method →
FEB and trigger Electronics →
Panel-shape 2-mm-thick 2-gapRPCs

	2-gap RPCs	4-gap RPCs
Thickness of single gaps	2.0 mm	1.0 mm
Total thickness of gas volume	4.0 mm	4.0 mm
$\langle q_e \rangle$ @ $HV_{\varepsilon=95\%}$	2.5 pC (Th~170 fC)	1.2 pC (Th~130 fC)
$\langle q_e \rangle$ at ~ 200 V > $HV_{\varepsilon=95\%}$	4.0 pC	1.5 pC
Type of resistive plates	HPL	HPL
Thickness of HPL	2.0 mm	2.0 mm
Resistivity of HPL	A few × 10^{10} Ωcm	A few × 10^{10} Ωcm
Current consumption per unit rate	~ 300 μA m^{-2} kHz^{-1}	~ 100 μA m^{-2} kHz^{-1}

2. Prototype 4-gap HPL RPCs

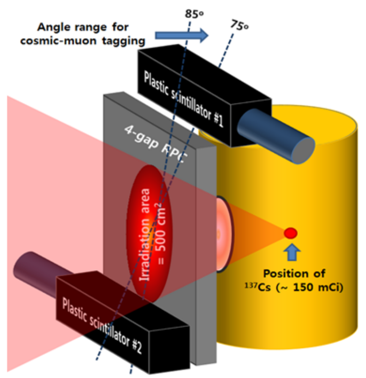
- ➤ Bulk resistivity of the HPL = ~ 2.7 × 10^{10} Ω cm (produced for CMS RPCs in 2007)
- ➤ Thickness of each gap (spacers manufactured from a PC panel) = 1.06 ± 0.01 (σ) mm
- ➤ Strip length = 45 cm
- ➤ Strip pitches = 14 mm for 32 anode strips
- ➤ Used a 32-ch FEE developed and currently being used for 2-gap CMS RPCs
- ➤ Digitization thresholds = 80 fC (140 mV), 130 fC (195 mV), 170 fC (220 mV)
- ➤ Gas mixture: 95.2% $C_2H_2F_4$ + 4.5% i-C_4H_{10} + 0.3% SF_6



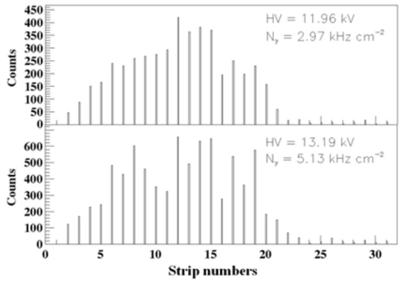


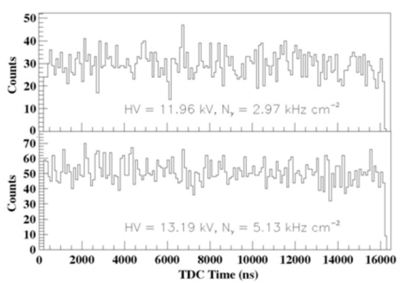
Installed the detector vertically to maximize the incidence of the gamma rays.
→ Muon-tagging angle = 75° ~ 85°

Data digitized at 130 fC
- ✓ with no gammas
- ✓ with gammas



Gamma distributions determined by fastest strip





5. Conclusions and Future Plans

Conclusions for the current R&D

(1) **Manufacture of detectors**

4-gap RPCs can be manufactured with the same technology used for the current double-gap RPCs in the CMS experiments.

- Each bi-gap gas envelope is composed of 3 HPL panels.
- The rest detector features are actually the same as the ones for the current double-gap RPCs.

(2) **Have tested the prototype detector** for muons and high-rate gamma background **using the current CMS-RPC FEE**

- Efficiency plateau > 800 V (confirmed)
- Rate capability > 5 kHz cm^{-2} (confirmed)
- Shifts in HV due to gamma rates: ~ 400 V at N_γ = ~ 3 kHz cm^{-2}
- Relevant digitization threshold for the current 1-mm thick 4-gap RPCs: 100 ~ 150 fC
  - ✓ Lower threshold → plateau size becomes smaller
  - ✓ Higher threshold → large shift of the operational plateau toward higher HV

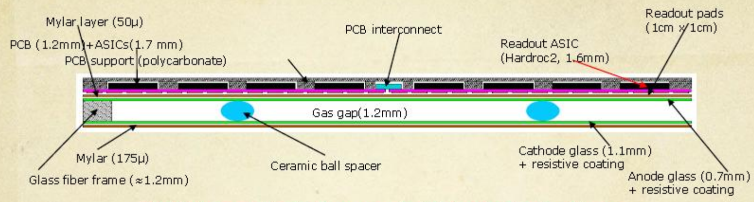
Future R&D plans for 4-gap RPCs: realistic R&D with real sized detectors

- ✓ Thickness of a single gap: 1.06 mm → 0.8 mm to get the working HV's around 9 kV. Spacers should be produced by a molding method.
- ✓ Aging study using gamma rays up to ~ 1 C cm^{-2}

IMAD, Laktineh (CNRS/IN2P3)

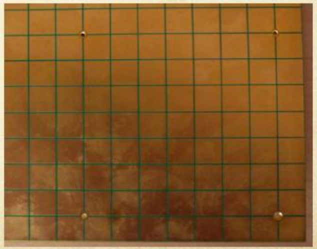
High rate, fast timing RPC for future LHC experiments upgrade

R&D on high rate RPC



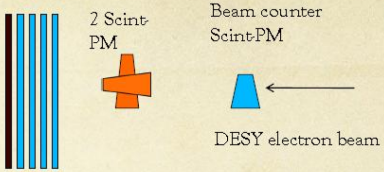
Total thickness (detector 3 mm+ readout electronics 3 mm): 6.0mm

Tsinghua glass (10^{10} Ω.cm)

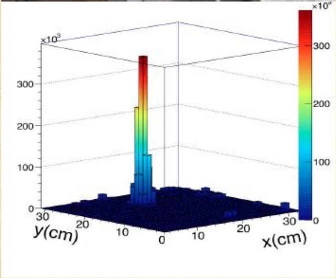


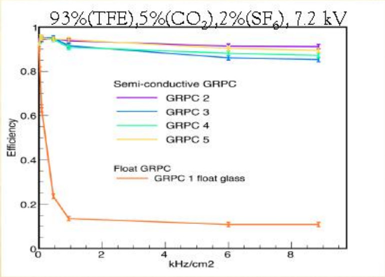
Same electronics readout used in the SDHCAL

R&D on high rate RPC



1 standard GRPC+ 4 low-resistivity GRPC





9 kHz/cm² is highest rate one can get at DESY

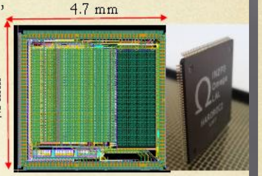
R&D on fast time RPC

If only 1-2 nanoseconds are needed then the first option is to use

-Use the HARDROC ASICs (well tested and available)
HARDROC : 64-channel, 2-bin readout (three comparators, 3 thresholds),
Dynamic range : 10fC-10pC.

- Use SDHCAL DAQ (available).

- Use a TDC with 100 ps time resolution (available) per ASIC
(use the U64 available signal for each of the three comparators as input)
- Design new PCB with pick-up strips (pitch of 2.5 mm)
on the two faces of the PCB with 1 mm staggering between the two faces.
ASICs are embedded on the PCB.



The new PCB can be used to equip the small GRPC already tested or new ones with the same electronics adding an external TDC and then use cosmic rays to check the sub-nanosecond time resolution.

Conclusion and perspectives

-R&D on high rate and fast timing GRPC is very active.

-High rate capability is demonstrated. Single–gap detectors using Tsinghua low-resistivity glass are still efficient with few kHz/cm2 rate.

-The exploitation of the excellent time precision the RPC could provide is pursued by developing/exploiting high performance TDC and ASIC. 10-20 timing precision seems to be reachable.

-The first aim of this R&D is to check the robustness of the proposal we made to equip the high η of CMS with cost-effective muon detectors capable of supporting high rate and providing timing information.

The time precision will allow to exploit fairly the fourth dimension. New area of applications could benefit form this developments: medical application, astroparticles….

WANG, Yi (Tsinghua University)

Study on high rate MRPC for High Luminosity Experiments

How to increase rate of MRPC

Voltage drop changes with rate:

$$\overline{V}_{drop} = V_{ap} - \overline{V}_{gap} = \overline{I}R = \overline{q}\phi\rho d$$

Four ways to improve rate capability:

- Reduce bulky resistivity of electrode glass
- Reduce the glass thickness
- Warming technology
- Reduce the charge

Wang Yi, Tsinghua University XII workshop on RPC and related detectors, Feb 23th- 28th . 2014, Tsinghua University, Beijing 11

Development of low resistivity glass

Components:
SiO2, Fe_2O_3, Na_2O, AL_2O_3, MnO_2

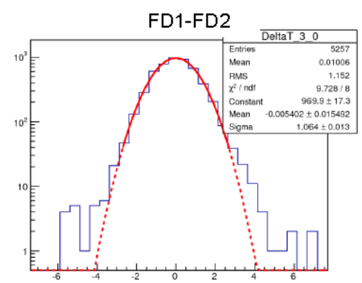
Glass resistivity: ~10^{10} Ωcm

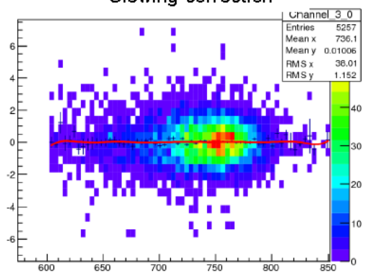
Process: Melting → Cooling → Cutting → Polishing

- Different compositions and related production procedures have been studied, yielding a tunable bulk resistivity in the range of 10^{10}–10^{11} Ωcm.
- In the mass production, in order to produce reliable glasses with high quality, surface measurement has been taken as a key part of the quality control.
- This glass shows a large stability against electrical stress.

Wang Yi, Tsinghua University XII workshop on RPC and related detectors, Feb 23th- 28th . 2014, Tsinghua University, Beijing

Performance of T0





Resolution of T0 (2.5σ): 1.06*24.5ps= 26ps

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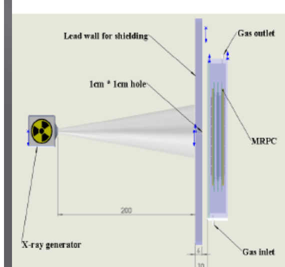
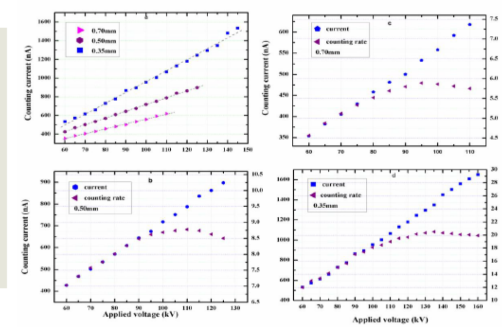
Rate test by X-ray





The maximum counting rate of 0.35MRPC is about 21 kHz/cm², which is 4 times higher than the 0.7MRPC and 3 times over the 0.5MRPC. It seems that the thinner glass electrode MRPC have a higher rate capability. But this estimate has to be validated through a detailed beam test.

Wang Yi, Tsinghua University XII workshop on RPC and related detectors, Feb 23th- 28th . 2014, Tsinghua University, Beijing

XIA, Lei (ANL)

RPC rate capability

- Particle flux through RPC → Signals → Current through detector, in particular through resistive electrode (glass/Bakelite) → Voltage drop on resistive electrode → Reduced voltage on gas volume → Lower gas gain, lower efficiency → limiting factor for rate capability
- For stable particle flux, after transient, the voltage on gas volume u_{1f} is *:

$$u_{1f} = \frac{u + 2cf\rho d_2 u_0}{1 + 2cf\rho d_2}$$

Constant ∝ signal charge
High voltage applied on RPC
Threshold voltage for signal to appear
Particle flux rate
Thickness of resistive electrode
Bulk resistivity of electrode material

- Ways to improve RPC rate capability
  - ρ↓: lower resistivity electrode material ← **Focus of this talk**
  - d_2↓: reduce thickness of electrode
  - c ↓: operate with lower gas gain, together with more sensitive readout

Development of low resistivity electrode material

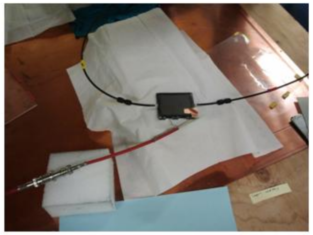
- We participate in the low resistivity Bakelite development led by USTC, China
  - Report this morning from Prof. Liang Han
- We are also interested in developing a low resistivity glass that could be produced at reasonable cost
  - More stable material properties, compare to Bakelite
  - Better surface quality and flatness
  - Low resistivity glass currently available (for example, from Tsinghua University) is quite expensive
- Argonne National Lab engaged Iowa University and COE College to develop low resistivity glass
  - COE College (Cedar Rapids, Iowa) is the expert is glass related research
  - Small samples made/tested at COE college in 2012
  - First 'large' samples made at COE college, tested at ANL in 2012 – 2013
  - Second 'large' samples made at COE college late 2013, being tested at ANL

Resistivity of the glass samples

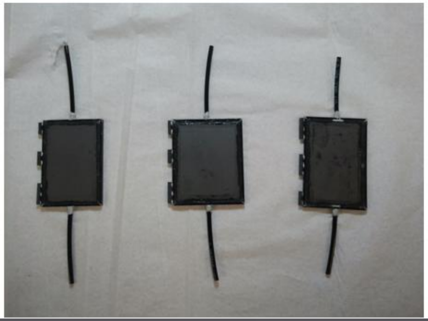
- 1st measurement was done with copper tape on rubber pad as probes
  - the contact to glass is not great, but can get a rough idea about the resistivity
  - ρ(sample1) = ~7x10^8 Ω·cm (R ~7 MΩ)
  - ρ(sample2) = ~6x10^8 Ω·cm (R ~ 8 MΩ)
  - This is right on target (10^8 Ω·cm)
- 2nd measurement was done with sprayed on graphite coating
  - Electrical contract is significantly improved
  - Both sample show very low resistance (~100 kΩ)
  - Seems like there are some very localized conductive path through the samples
- Other issues with the two samples
  - Some visible inclusions and bubbles
  - Unfinished polishing on one side of sample 2, and overall finish is not very good
- We went ahead to make a small RPC, knowing it will fail…

RPC prototype

- We managed to cut out 3 pairs of rectangular pieces out of the large fragments, all about 4 cm x 6 cm
- 3 small prototype RPCs were built and HV tested – all of them can hold > 7 kV with minimum dark current. No sign of any break down / spark.
- The gap size is ~1.1 to 1.2 mm, a decent avalanche signal should show up at ~ 6.3 kV, with ~90% efficiency using DHCAL readout
- Due to the small size of these RPCs, we plan to skip cosmic ray tests and go directly to test beam at Fermilab.



HV test



LIBERTI, Barbara (INFN, Tor-Vergata)

New RPC gas mixtures for large area apparatuses

New Gas Tetrafluoropropene ($CHF=CHCF_3$)

GENERAL PROPERTIES

Molecule	Honeywell HFO-1234ze Blowing Agent trans – 1,3,3,3-tetrafluoropropene
CAS #	1645 – 83 – 6
ELINCS # (EU)	471 – 480 – 0
Formula	trans – $CHF=CHCF_3$
Molecular Weight	114
Boiling Point	- 19° C
Vapor Pressure @ 25° C	490 kPa
Vapor Pressure @ 55° C	1080 kPa
Liquid Density @ 25° C	1.18 gm/cm³
Vapour Thermal Conductivity	13.0 mW / m• °K (@ 25°C)
Flame Limits	None to 30° C
Ozone Depletion Potential	Zero (non-ODS)
Global Warming Potential	6 (100 yr time horizon)

It can easily replace HFC- 134a

It is not flammable

It has a safe use

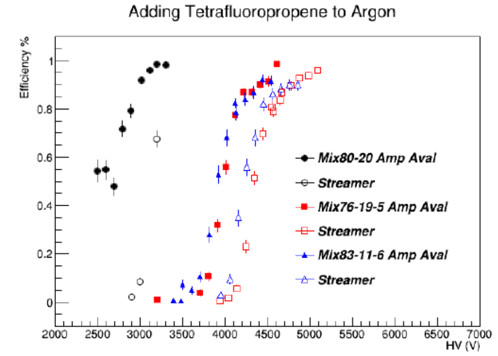
Environmental acceptability (low GWP)

Compatibility with materials commonly used

Compatibility: The product does not present any particular problems of compatibility with materials (plastics and elastomers) and is similar to R134a

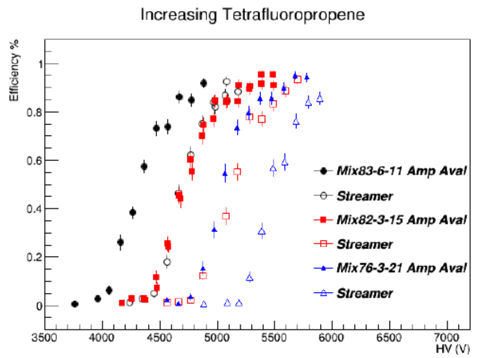
Security: HFO- 1234ze , the reference ambient temperature (21 ° C) is not flammable , according to the ASTM Method E-681 and the EU Test A-11

Adding Tetrafluoropropene 1.



All mixtures of gases are composed by Argon, Isobuthane and Tetrafluoropopene And are referred to with name "Mix %Argon-%Isobuthane-%Tetrafluoropropene"

Increasing Tetrafluoropropene 1.



Conclusions

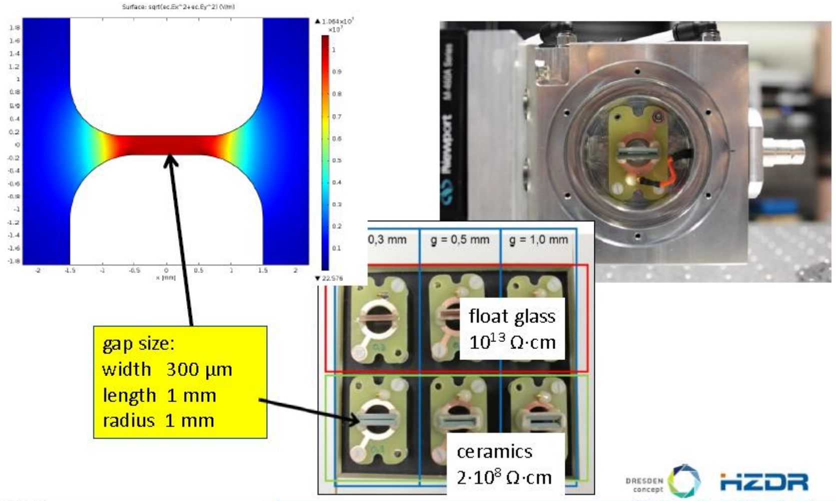
These very preliminary results show that:

- Tetrafluoropropene has shown a very strong effect both in quenching and in keeping the charge at low level
- Mixtures like Ar-Iso-Tetra=82-3-15 are adequate for streamer working mode with very modest delivered charge. The small loss of efficiency could be compensated by a larger gap size
- These mixtures are promising even for avalanche working mode with an appropriate FE Electronics and a dedicated chamber layout

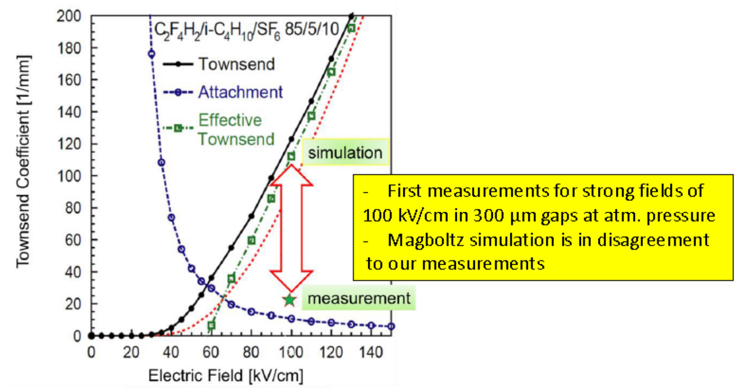
NAUMANN, Lothar (HZDR)

Precision measurement of Timing RPC gas mixtures with laser-beam induced electrons

RPC probe



Effective Townsend coefficient

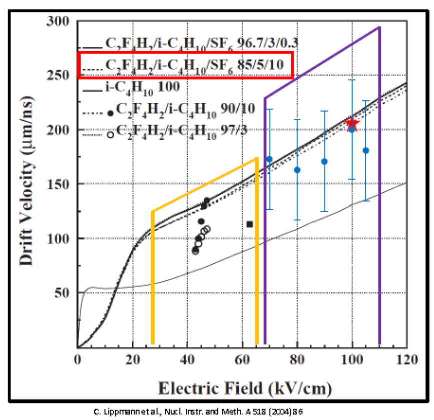


C. Lippmann et al., Nucl. Instr. and Meth. A 518 (2004) 86

Electron drift velocity

our measurements:
- 0,3 mm; float glass
- 0,3 mm; SiN/SiC

First measurements at 100 kV/cm in 300 µm gaps at atm. pressure
Magboltz simulation is in agreement to our measurement



C. Lippmann et al., Nucl. Instr. and Meth. A 518 (2004) 86

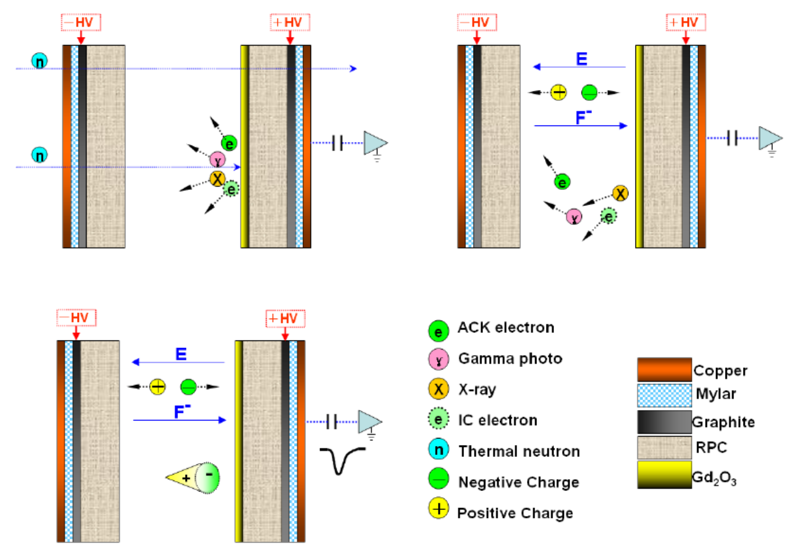
Summary

- **Timing RPC** successfully probed in a table-top laser facility (300µm; 100kV/cm; 1atm.)
- **Eff. Townsend coefficient** for Freon/SF_6/IB is in disagreement to Magboltz simulation
- **Electron drift velocity** in Freon/SF_6/IB is in considerable agreement with simulation
- **Signal time spread** shows no sufficient figure of merit

NING, Zhe (IHEP)

The RPC-Gd for Large Area Thermal Neutron Detector

The operation mode of RPC-Gd for thermal neutron detection



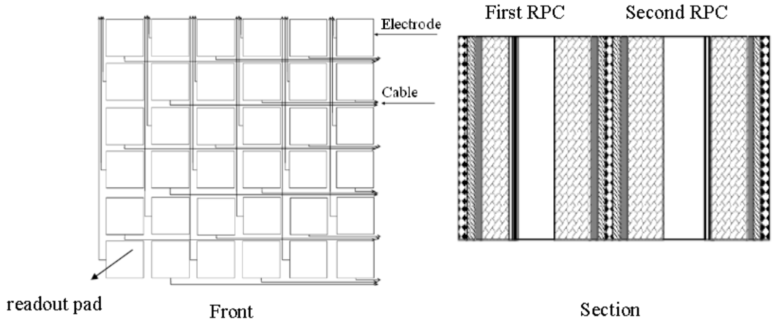
Double layers RPC-Gd for γ and neutron discrimination

① The operation HV for two chambers is different ;

② The differences can be 500 ~ 1000 V;

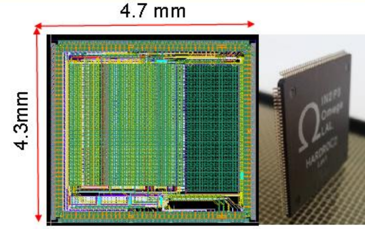
③ If there are only gamma rays, the amplitude of first RPC is the same with the amplitude of second RPC;

④ If there are thermal neutrons, the amplitude of first RPC is different from the amplitude of second RPC.



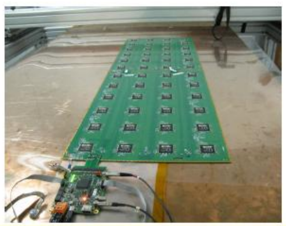
ASIC readout for the prototypes electronics

ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction => uniformity
Power-Pulsed (7.5 mW in case of ILC duty cycle)



Tiny connectors were used to connect the PCB two by two so the 24X2 ASIC are daisy-chained.

DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.



Data and pictures are Copied from:Han ran,The Institute of Nuclear physics of Lyon, Villeurbanne, 69622,France;School of Nuclear Science and Engineering, North China Electric Power University, Beijing

Summary

1. Advantage of RPC-Gd

① Easy for n/γ discrimination;

② The coat of Gd-oxide is easy to be produced and cheap;

③ RPC can cover large surfaces;

④ The production technology of RPC is mature;

⑤ RPC is cheap and can be used for mass production.

2. Application prospect

① Neutron dose detection for evaluating neutrons around accelerator;

② Imaging, such as container examination;

③ Synchronous radiation and space detectors.

Developments of Oil-free Bakelite Resistive Plate Chambers for Particle Physics Experiments:

- BESIII experiment
- Daya Bay experiment
- Digital Hadron Calorimeter

IMPORTANT CONCLUSIONS

◆New smoother mold improves the surface quality and reduces the noise rate significantly.

◆Recommend to run at HV=6.5kV, Th=110DAC (230fC):

I. Efficiency: >90%,

II. Noise rate: ~0.3Hz/cm^2(RPCs using old plates ~0.5Hz/cm^2)

III. Pad multiplicity is a function of surface resistivity on readout side.

IV. 2nd batch: ~1.5, 1st batch: ~1.7-2.1

◆ No obvious areas of inefficiency

◆ Bulk Resistivity: 2×10^{11} - 2×10^{12} Ω·cm

◆ Surface Resistivity: 2×10^{6} - 1×10^{8} Ω/ -

◆Operational Conditions: 8kV HV, 100mV Threshold, and $Ar:C_2F_4H_2:C_4H_{10}$ = 50:42:8

◆Mean Efficiency: 95.4% for bare RPCs, 96.9% for super layers

◆Mean Noise Rate: 0.18Hz·cm^{-2} for bare chambers

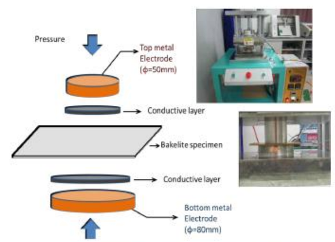
◆Total Area: ~1273 m^2 for bare chambers

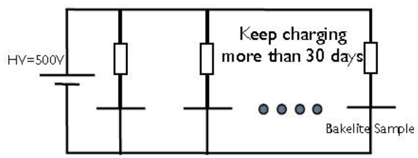
HAN, Liang (University of Science & Tech. of China)

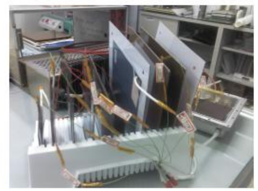
Study on low resistivity Bakelite RPC

Bakelite Aging Study

- Both bulk and surface of different kinds of resistivity bakelite samples are investigated. The resistivity of the samples are $10^9 \sim 10^{12}$ Ω·cm, thickness 1mm~2mm.
- Aging study has been researched in 2 ways.
  - Long time stability (~1 year), temperature 20°~25°, humidity 30%~50%
  - High-rate working condition imitation, around charge flux, ~2C/cm².



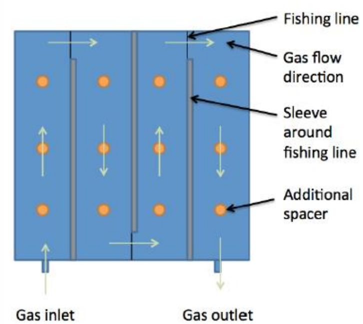


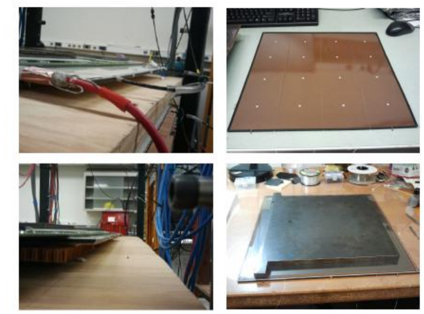


Low Resistivity RPC

- Basic design is the same as the DHCAL glass RPC, with some modifications

  -----Use extruded PVC frame, which defined the gap size (~1.2mm)
  -----Added insulation for electrical contact with the embedded graphite layer
  -----Added spacer between fishing lines to deal with board warpage



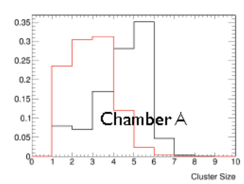


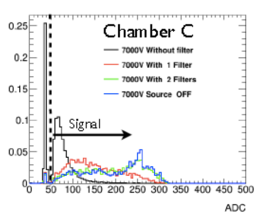
GIF Test Results

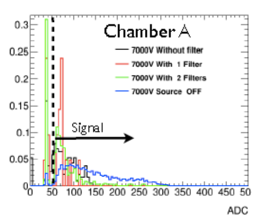
- Both 2 kind of low resistance RPC have been test at GIF

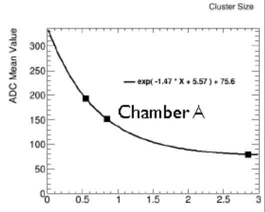
  -----Signals could been observed with MDT DAQ system, but the signal size is reduced against the strength of the source
  -----Multiplicity is decreased obviously due to the smaller signal size when the source is on.
  -----The dark current is at reasonable level. (~10μA)
  -----Time Resolution can reach nano second level, can't get precision results because of the DAQ system limitation.

Red Line: Source On
Black Line: Source Off









Conclusion

Effective low resistance RPC to work at high rate condition

$$\downarrow R = \frac{\rho \times d}{s}$$

1. New material ($\rho = 10^{12}$ -> 10^9 Ω·cm) : stable stored still, need more investigation for radiation tolerance.
2. New bakelite plate structure (carbon electrode embedded, d=2mm -> 0.1mm): work well as traditional RPC, more research is ongoing.

- New sensitive readout electronic is under study for RPC working at high rate.

HAN, Ran (North China Electric Power University)

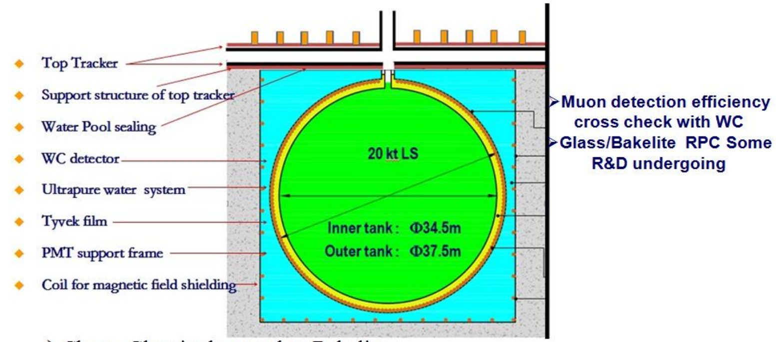
Performance of RPC made by different kind of glass

Jiangmen Underground Neutrino Observatory

θ_{13} DYB

JUNO: Mass Hierarchy etc…

Top Tracker with RPC R&D



- ➢Cheap: Glass is cheaper than Bakelite
- ➢Good performance, Uniform
- ➢Low noise rate: Glass is very flat

} Glass RPC is a better choice

- ➢**Robust:** Strengthen glass
- ➢**Reduce humidity in Chamber:** Gas tuber or Acid resistance glass

The Different Glasses

	Float glass (ASAHI glass)	BF33 glass (SCHOTT BOROFLOAT 33 Borosilicate Glass)	Gorilla glass (Corning)	Strength glass
Volume resistivity	~$10^{12}\Omega$.cm	~$10^{15}\Omega$.cm	~$10^{14}\Omega$.cm	~$10^{14}\Omega$.cm
Standard sizes	---	1150x850 cm^2	1244x1092	1244x1092
minimum thickness	0.7mm*	0.7mm*	0.5mm **	0.7mm
Special Properites	---	**Robust,** highly resistant to water, **strong acids,** alkalis as well as organic substances,**good surface quality**	**Robust**	**Robust**

Float glass in Potassium nitrate solution,
In surface, Na+ replaced by K+
The thickness of replace surface
from 30 μm to 50 μm

* Usually we can get from the market

Summary

- **The volume restivite**

BF33 > Gorilla(strength) glass > ASAHI glass

- **The voltage to reach plateau**

BF33@8200V,Gorilla(Strength)@7800V, ASAHI @7300V

- **The Price**

BF33~Gorilla >> Strength~ASAHI

- **The Properties**

Robust: BF33~Gorilla~Strength > ASAHI
Resistant to acid: BF33

Strength glass and float glass as a choice bfor larger area RPC production, **Reduce humidity** should be in other way.b

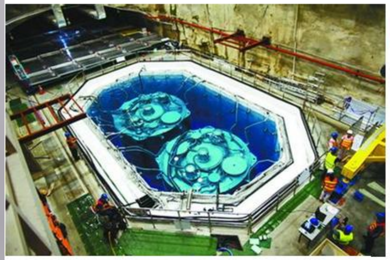
Next:

- ➢ The 1m² chamber with float glass and strength glass is ongoing
- ➢ The Front-End Electric borad will be provide by USTC
- ➢ The Prototype will to DYB to do underground experiment

XIE, Bo (Tsinghua University)

A new type of RPC for the VETO of JUNO

Problems

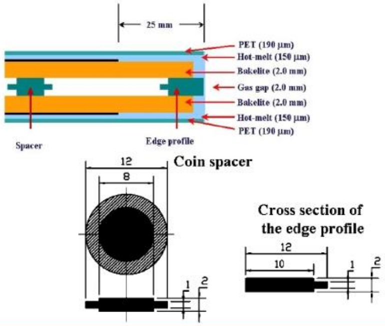


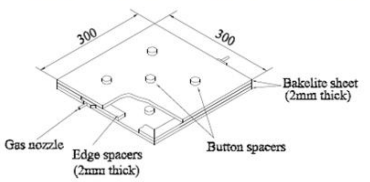
Environment:

1、moist

2、radiation background (^{40}K ^{232}Th ^{238}U)

3、…

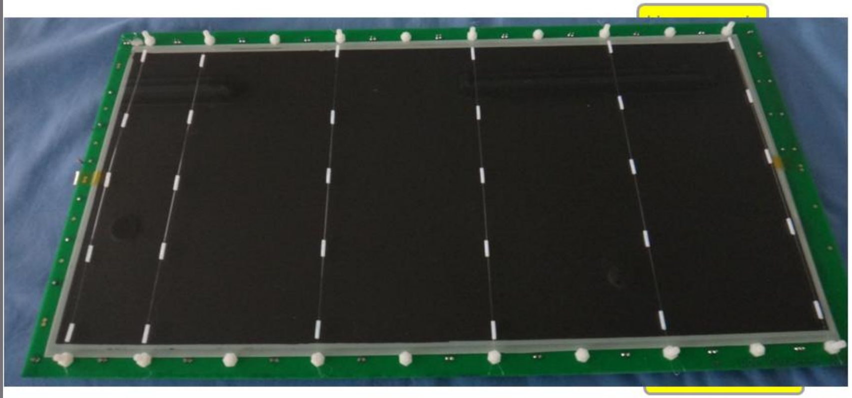




Biswas,S. et al. Development of bakelite based Resistive Plate Chambers. arXiv:0802.2766 [nucl-ex]

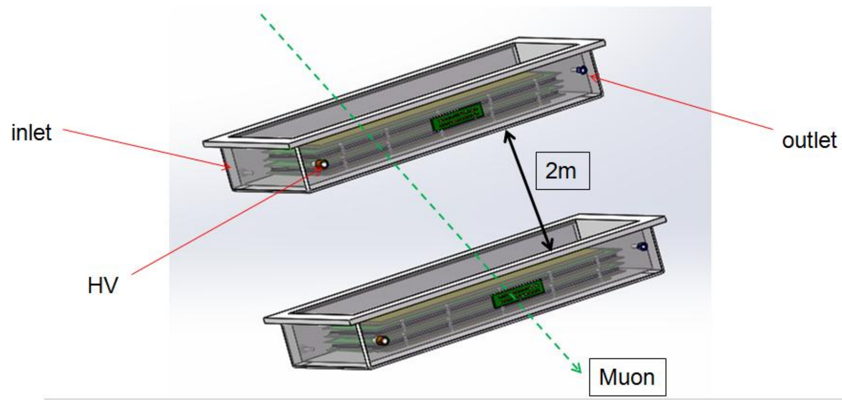
S.Park et al. Production of gas gaps for the Forward RPCs of the CMS experiment. Nucl. Instr. Methods A550(2005) 551-558

Development of one-dimension RPC



Necklace spacer: 10mm PTFE tube + fishing line， dead area：<1%

The super module of VETO



The whole VETO consists of four layers of RPC (1.2m ×1.2m), at least 3 RPCs have signals if a muon pass through.

Compared with one dimensional RPC with same layers, it has higher efficiency.

Advantage of this type RPC

1、The glass is very flat and has weight. It is just put on the spacer, no glue.

2、The RPC is reinforced by two honeycombs, no distortion.

3、The spacer is ϕ2mm PTFE tube. Its uniformity is excellent and commercially available. Dead area is smaller than cylindrical spacer.

4、There is no glue on spacer and will not cause extra noise.

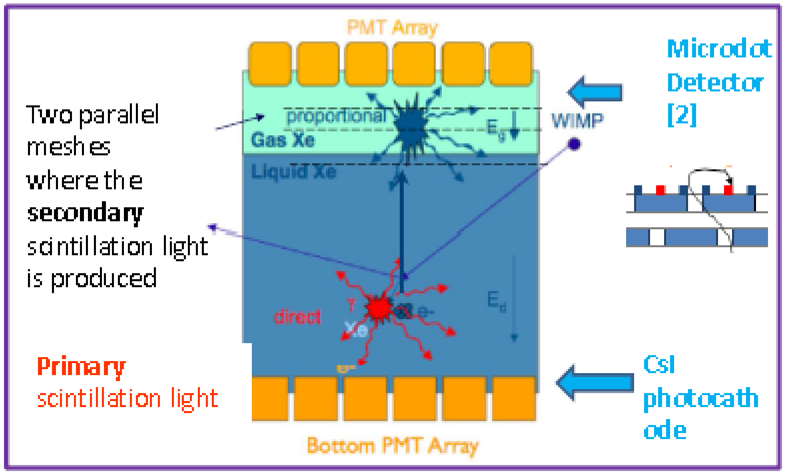
5、This RPC is open and has to be put in aluminium gas tight box. This is propitious to gas diffusion. And RPC is isolated from environment by box so it will not be affected.

FONTE, Paulo (LIP)

Development and first tests of microdot detector with resistive spiral anodes

Possible application: dual phase **liquid dark matter detectors**. From the ratio of **primary/secondary** lights one can conclude about the nature of the interaction.

- In order to lower the cost of the device: reduce the number of PMTs. Replacement of bottom PMTs by CsI photocathode [1], but problem of photon feedback.
- Replace the meshes with a microdot detector where amplification region is geometrically shielded from CsI [2]



Goal of this work: to improve performances of microdot detectors.
Geometry: resistive spiral anode, readout strips below anodes. Signal recorder by capacitive coupling.

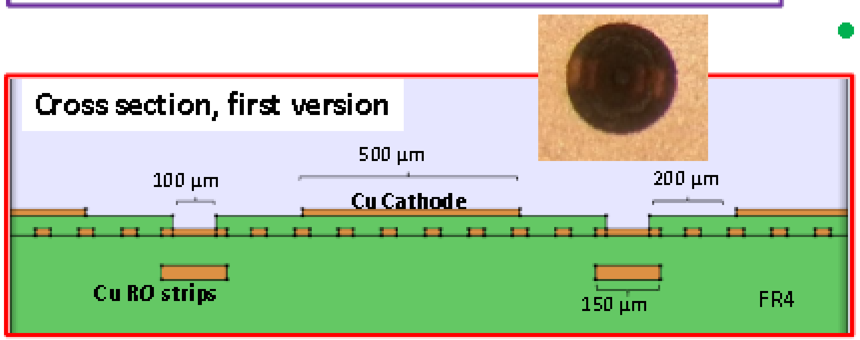
Advantages of this geometry:

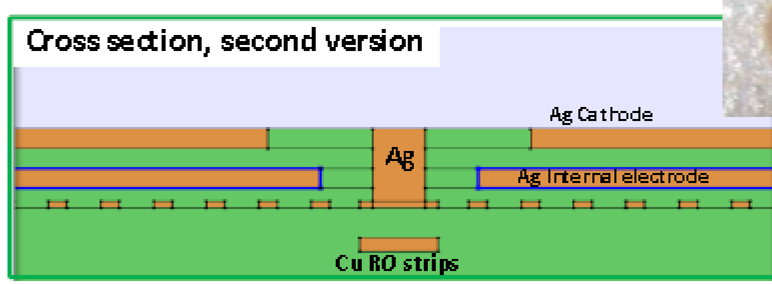
- electric field more azimuthally symmetric
- spark protection due to the high resistance values in the anodes (GΩ)
- decoupling of anodes from readout: possibility to do 2D readout

So far we built two different versions, but results only from the fist one.

In the second version:

- same gap (200 μm), anode width (100 μm) and pitches (1 mm) as first version
- different geometry : anode and cathode all in the same plane
- addition of an internal electrode to better shape electric field on the surface
- Silver electrodes , easy to built



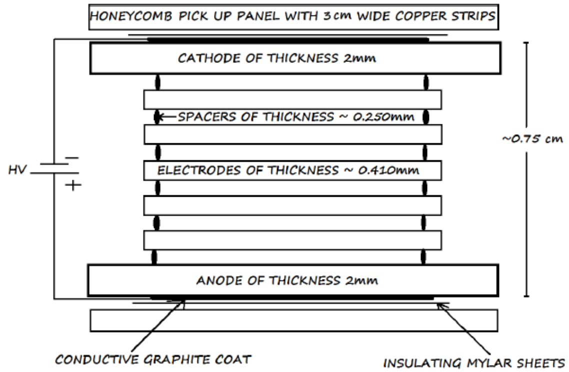


DEVI, Moon Moon (TIFR)

Performance Study of Glass Multigap RPC Detectors

Development of MRPC (6-gap) at TIFR.

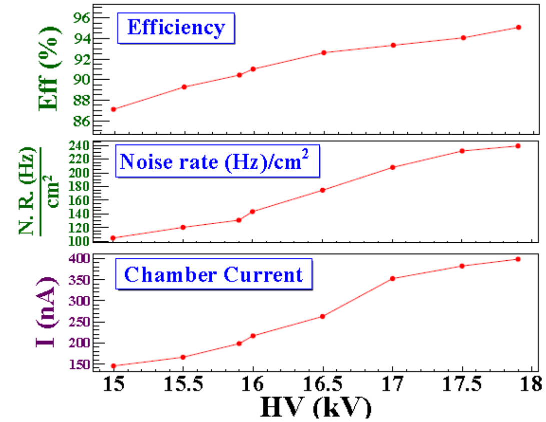
The schematic diagram of the structure:



Top and Bottom Electrodes are of thickness 2 mm. Inner electrodes are ~ 0.410 mm thick. Spacer thickness ~ 0.250 mm.

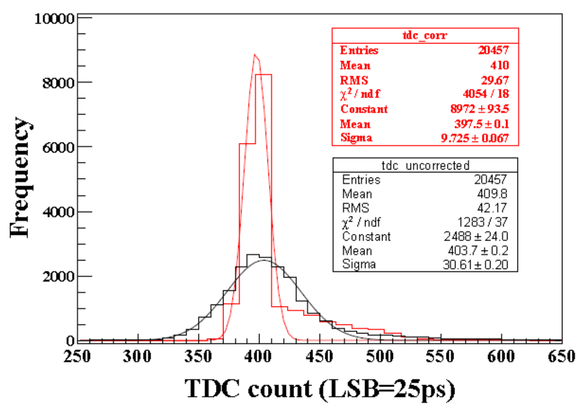
Characterization

Gas composition: R134a(91.06%), C_4H_{10}(4.94%), SF_6(4%)



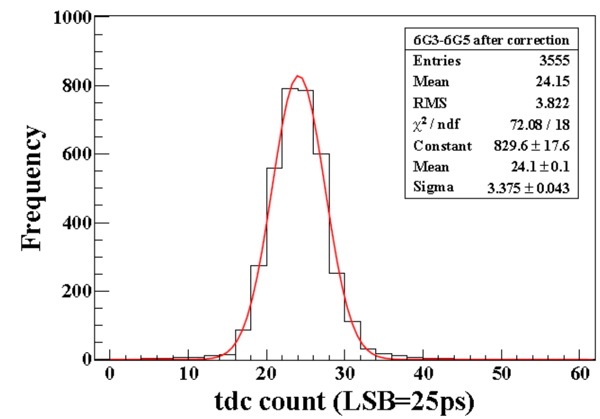
HV: Reasonable noise rate and chamber current at 17.9 kV

Correcting the timing distributions for time walk



After applying this correction the timing of an MRPC at 17.9 kV improves to 243 ps from 765 ps

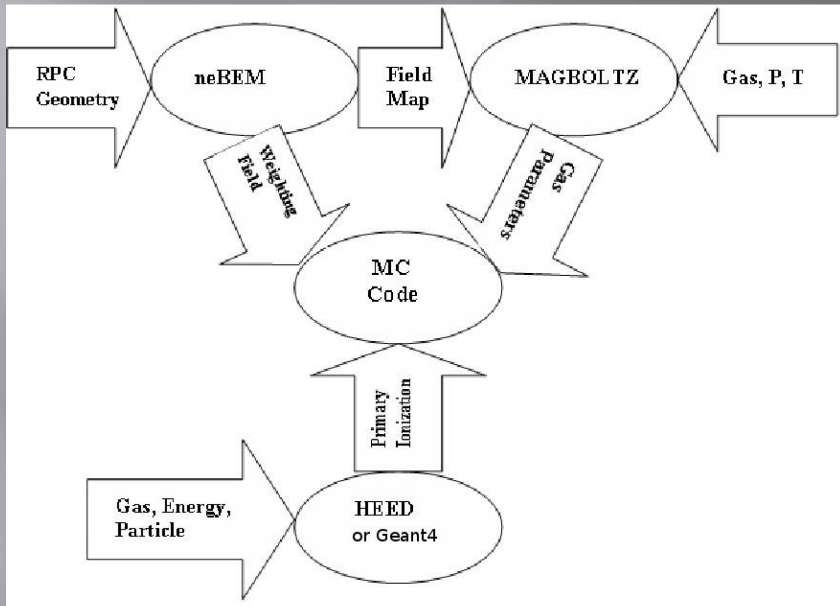
Time resolution



Time resolution 84.4ps at 17.9kV, electronic jitter (15–25)ps

SALIM, Mohammed (AMU)

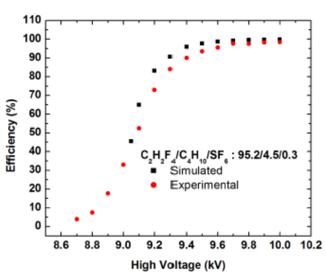
Simulation of Efficiency and Time resolution of Resistive Plate Chambers and Comparison with Experimental data



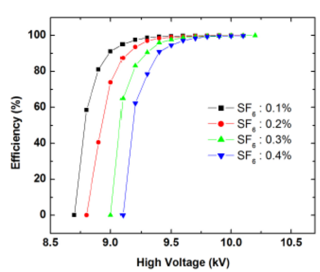
Gas parameters

- Drift velocity increases linearly with electric field.
- Townsend coefficient (which is the measure of ionization) also increases with electric field.
- Attachment coefficient decreases with the electric field which is very high at low voltages for SF_6 based gas mixtures. These are avalanche gas mixtures.
- Attachment coefficient not varying much with electric field for Argon based gas mixtures. These are streamer gas mixtures.

Efficiency

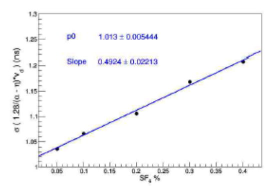


(a) Comparison of experimental[2] and simulated efficiency.

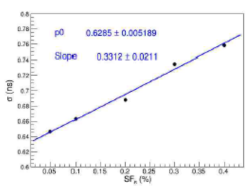


(b) Simulated efficiency.

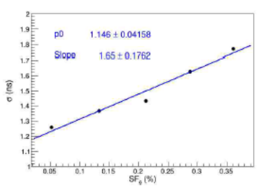
Timing



(a) Simulated time resolution[3]



(a) Simulated time resolution[1]



(b) Experimental time resolution[2]

Correction of the operating point as function of SF6 is yet be applied.

Plan of the talk

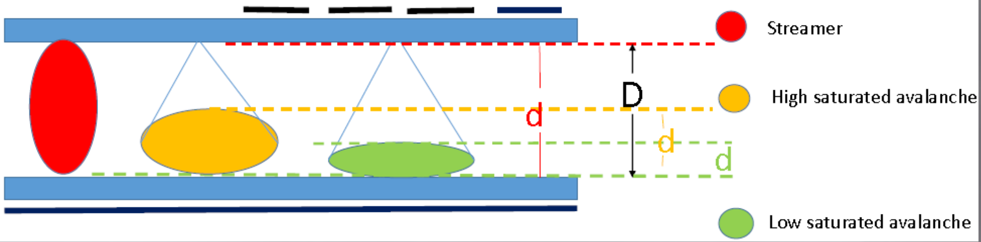
- Introduction
- Detector R&D
- Signal Readout
- Detector performance
- New deployments
- Applications
- Outlook

CARDARELLI, Roberto (INFN, Tor-Vergata)

Electronic charge (Q_{el}) to ionic charge (Q_{ion}) ratio

$Q_{el}/Q_{ion} = d/D$

$Q_{tot} = Q_{el} + Q_{ion}$



- threshold $\cong 0.1 \cdot Q_{el}$ (98% of efficiency) and V_{th} at 5σ over the front-end noise

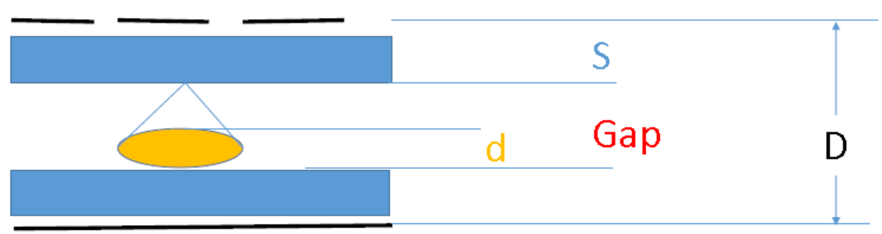
Noise of the front end = $Q_{el} \cdot 0.1 \cdot 0.2$

For streamer $N \cong 10^{-10} \cdot 0.1 \cdot 0.2 = 2 \cdot 10^{-13} < 5 \cdot 10^{6}\ e^{-}$ rms

For high saturation $N \cong 2 \cdot 10^{-12} \cdot 0.1 \cdot 0.2 < 2 \cdot 10^{4}\ e^{-}$ rms

For low saturation $N \cong 2\ 10^{-13} \cdot 0.1 \cdot 0.2 < 2 \cdot 10^{3}\ e^{-}$ rms

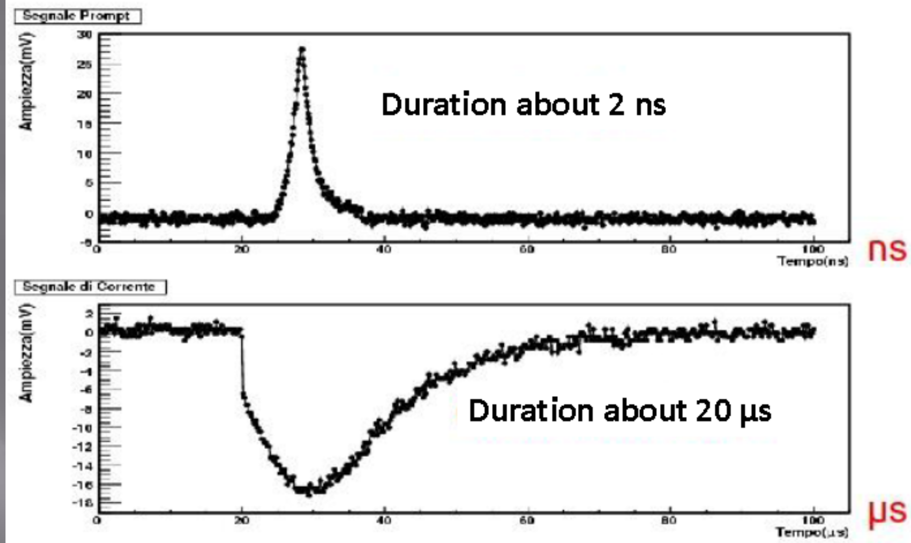
Qth streamer < $2.5\ 10^{7}\ e^{-}$; Qth high saturation < $10^{5}\ e^{-}$; Qth low saturation < $10^{4}\ e^{-}$



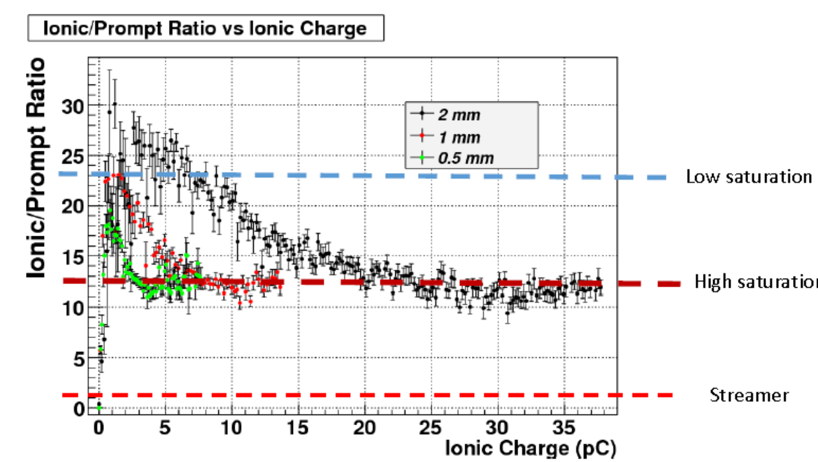
$Q_{tot} = Q_{ion} + Q_{el}$

$Q_{el}/Q_{tot} = d / (2 \times S/\varepsilon_r + G)$

Prompt signal and ionic signal



Q_{ion}/Q_{el} ratio for RPCs with different gap



CARDARELLI, Roberto (INFN, Tor-Vergata)

The RPC performance is strictly connected to the gap thickness, resistivity and surface of the electrode, pick-up design and front-end electronics performance.

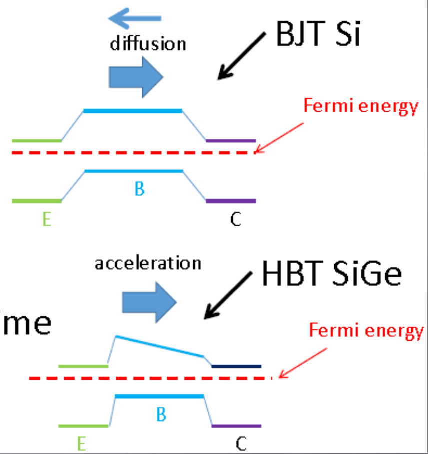
B JT performances

- $\beta = \tau_c / \tau_t$
- $f_t = 1/\tau_t$
- $N = K^* \tau_t$

τ_c = base life time

τ_t = base transient time

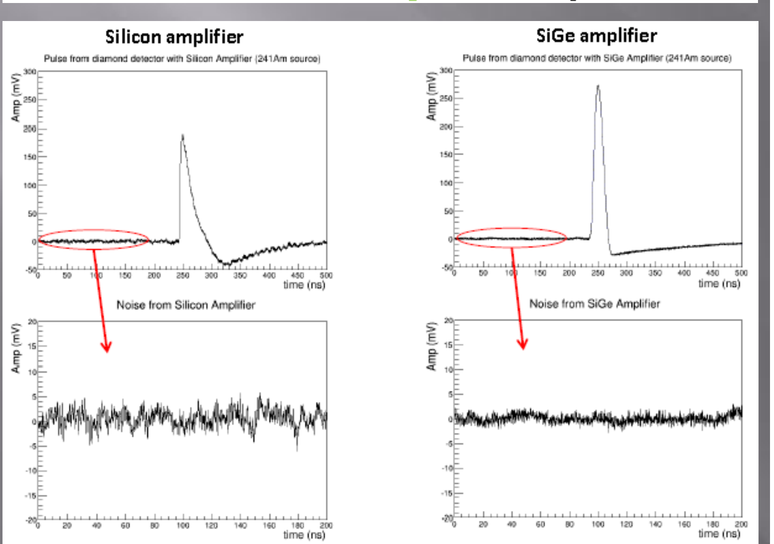
τ_t (Si) >> τ_t (SiGe)

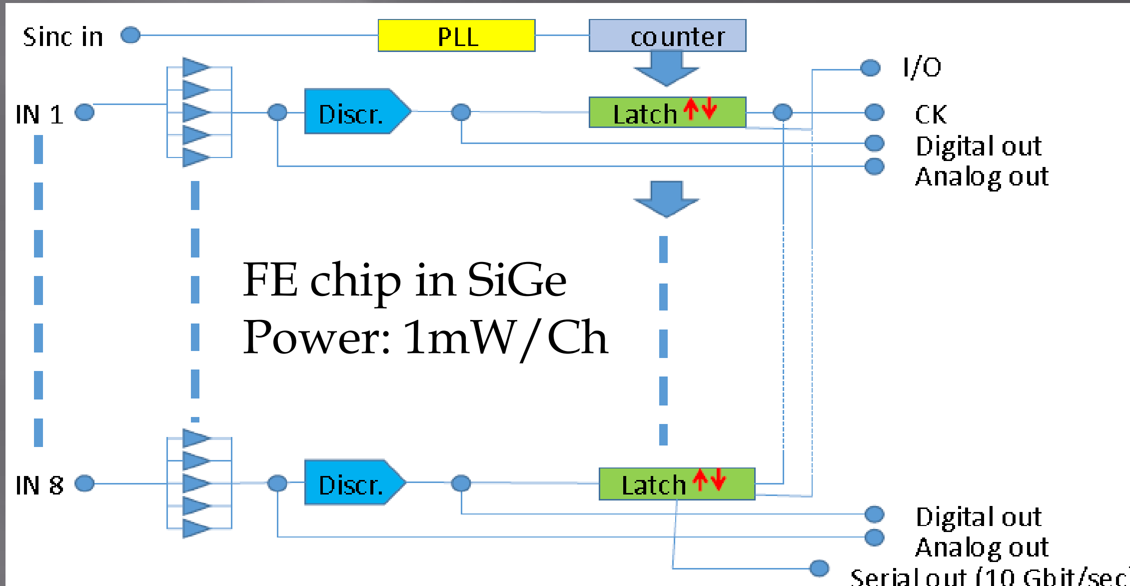


Parameters for optimization of the RPC

- To optimize the RPC performance four elements are considered

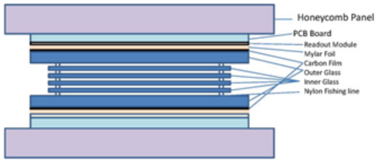
1. The working mode: Q_{el} (rate capability and aging)
2. The pick-up geometry: d/D (maximize Q_{el}/Q_{tot})
3. The Front-End performance: A_{FE} and Bandwidth
4. The Gap: for the timing, T_{el} (Time resolution and rate capability)





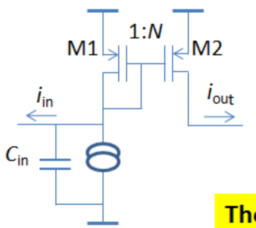
A fully current-mode ASIC For MRPC-TOF Application

- **CAD: A Fully Current-Mode Structure for MRPC (Multigap Resistive Plate Chamber) Time of Flight Measurement**



- **Features of MRPC detectors**
  - High detector efficiency
  - Good time resolution
  - Suitable for large-area TOF measurements for particle identification

⇨ The Front-End Electronic must be **high time resolution, high bandwidth, multi-channel readout, ……**



Why current-mode structure?

- Supply voltage decrease
- Open-loop current amplifier is easy to be high bandwidth, thus less stability problem

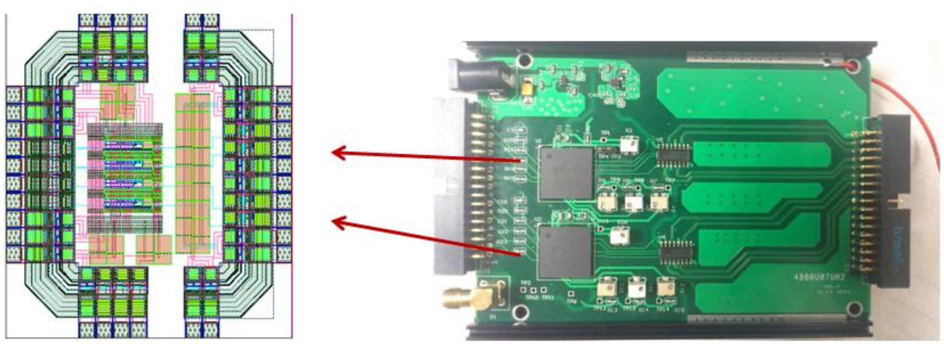
The problem is the time jitter analysis of current-mode discriminator is not mature

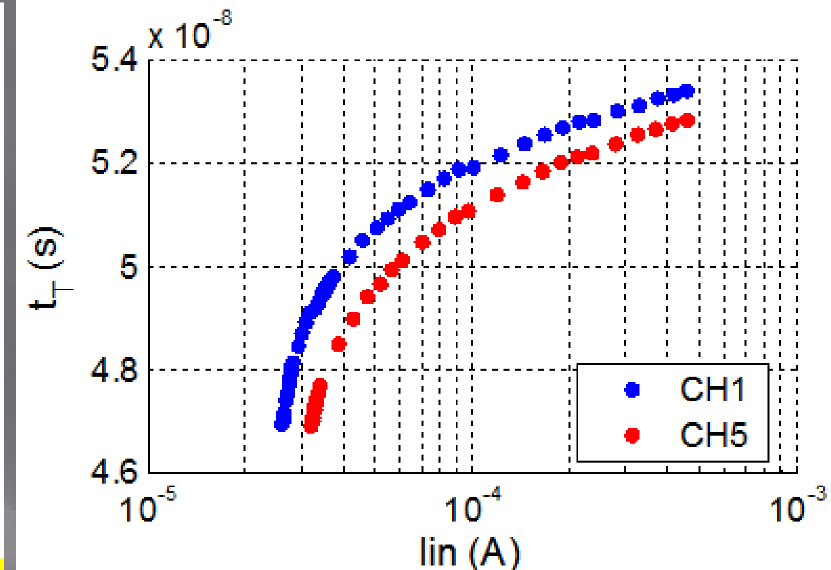
CAD (Current-mode Amplifier and Discriminator)

- 4-CH readout ASIC
- Special BGA package
- 3.3V supply voltage
- Single-end input, single-end logical output

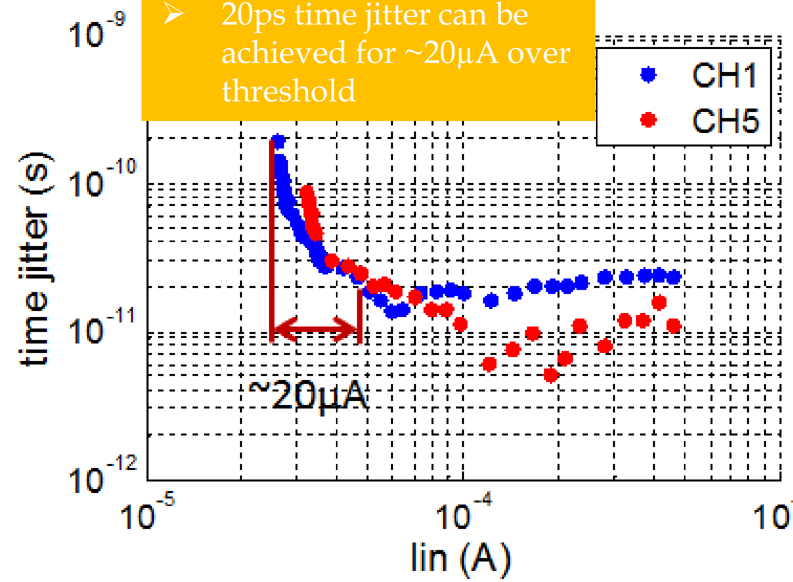
PCB

- 8-CH PCB test board
- Single-end input, LVDS output





- 20ps time jitter can be achieved for ~20µA over threshold

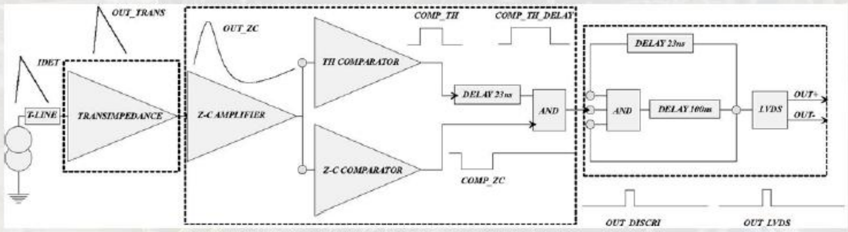


JOLY, BAPTISTE (CNRS/IN2P3)

Upgrade of the ALICE Muon Trigger Electronics

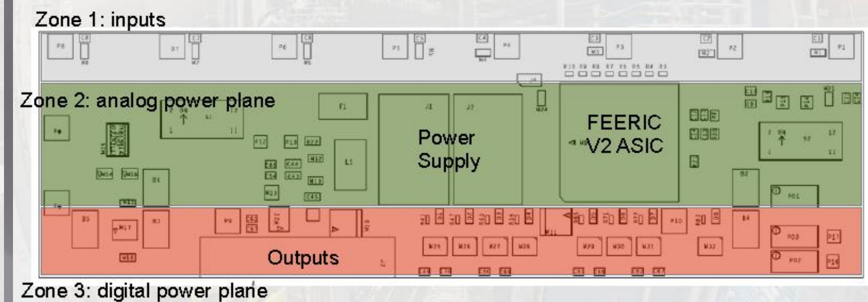
FEERIC v1 ASIC overview

- Transimpedance amplifier (both polarities)
- Zero-crossing discriminator for limited time walk and optimal time resolution
- One-shot (prevents retriggering during 100 ns)
- LVDS outputs



FEERIC v2 board layout

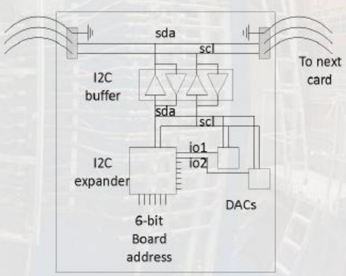
- Input area (zone 1):
  - For noise limitation: input of printed circuit tracks shielded by ground planes. No power plane.
  - For minimal cross-talk: input tracks alternated in 2 layers isolated by a ground plane
- Separate analog and digital power planes
  - better voltage regulation and lower noise required on the analog vs. digital area



"Extended" FE Boards configuration with I2C serial bus

- Analog threshold voltage distribution presently in ALICE cavern
- Digital control foreseen for the upgrade : more flexible and reliable
- Many commercial ICs (eg DACs) are programmable by I2C, a simple and robust serial bus

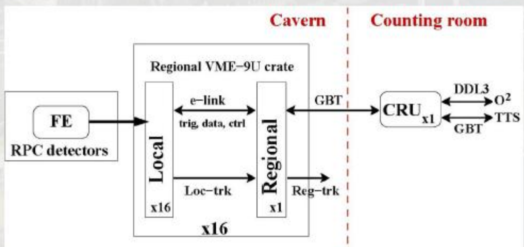
- Attempt to chain up to 26 FE boards (max. on one RPC side in cavern) on the same bus
  - Electrical limitation
    - Bus line capacitance too high
    - Need for a bidirectional I2C buffer for driving the line
  - Addressing limitation
    - Most ICs have only 3 address bits => allow to chain 8 FE boards max
    - It is foreseen to test an expander with 6 address bits



I2C bus interface and board chaining

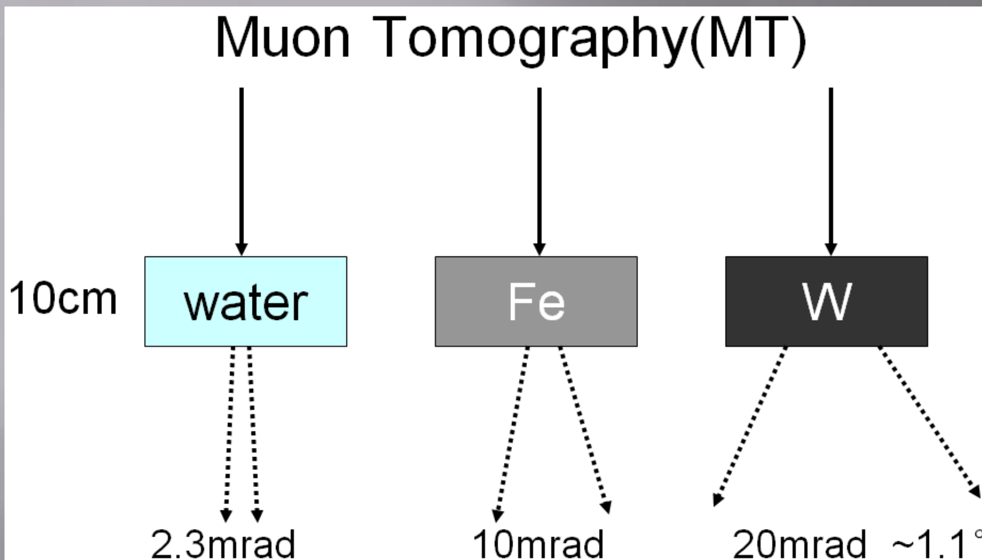
Readout Electronics Upgrade

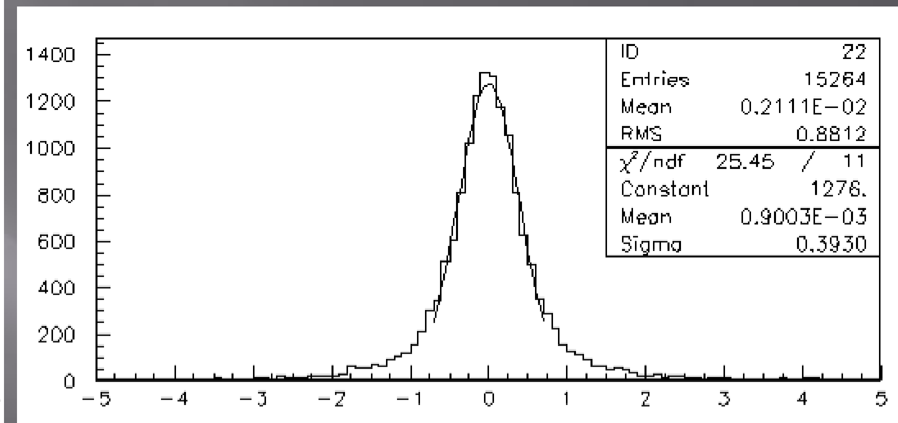
- Dead-time free readout up to 100 kHz in Pb-Pb (x100 above present design), ~300 MB/s
- Replacement of the **234 LOCAL cards** and of the **16 REGIONAL cards** presently installed
  - Transfer LOCAL - REGIONAL via e-link (320 Mbit/s)
  - Transfer REGIONAL - CRU (ALICE Common Readout Unit) via optical GBT link (3.2 Gbit/s)
  - Data sent to O^2 computer farm, for online reduction and transmission to storage



Present LOCAL card

Improving the Spatial Resolution and Muon Tomographic Imaging Properties of the Delay-line Readout Glass RPC

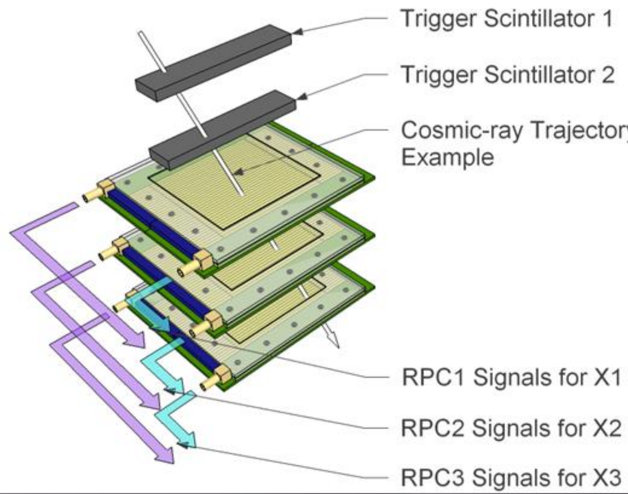




$$f = X_2 - (X_1 + X_3)/2 \quad \text{ex3}$$

Residual Method

$\Delta X = X_2 - (X_1 + X_3)/2$



2.54 mm pitch readout strips

$$\sigma^2 = \sigma_{x2}^2 + \left(\frac{1}{2}\right)^2 \sigma_{x1}^2 + \left(\frac{1}{2}\right)^2 \sigma_{x3}^2 = \frac{3}{2}\sigma_x^2$$

$$\sigma_x = \sqrt{\frac{2}{3}}\sigma = 0.816 \bullet 0.393mm = 0.339mm$$

$$FWHM_x = 2.35\sigma_x = 0.753mm$$

A multiplex readout method for large-area position sensitive MRPCs for cosmic muon detection

- The mathematical model

If n is an even, stripe n is connected to Aa, where

$$a = \frac{n}{2} \bmod n_a$$

Otherwise, n is an odd, stripe n is connected to Bb, where

$$b = \frac{n-1}{2} \bmod n_b$$

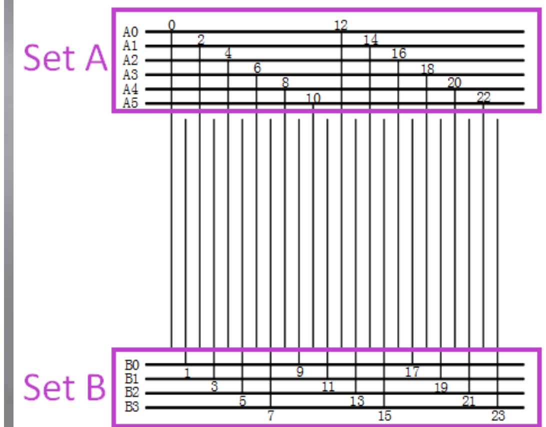
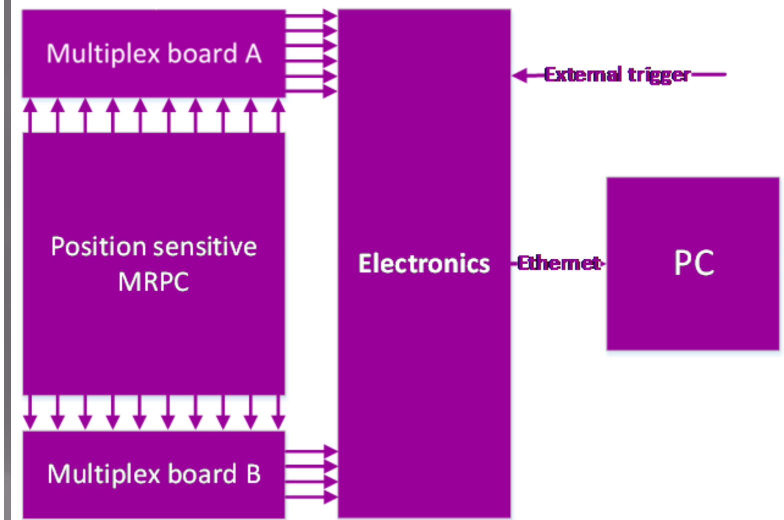


Fig. An example of fine-fine anode geometry



two adjacent stripes

(n,n+1) → (Aa,Bb)

(0,1) → (A0,B0)

(1,2) → (A1,B0)

(11,12) → (A0,B1)

...

It can be mathematically proved that mapping is injective if and only if

$$\gcd(n_a, n_b) = 2$$

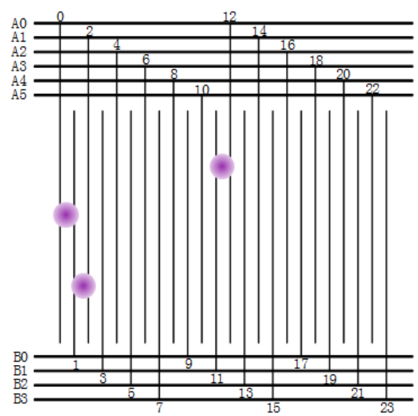


Fig. An example of fine-fine geometry

lookup table for 2 adjacent pickup stripes.

	A0	A1	A2	A3	A4	A5
B0	0	1	16	17	8	9
B1	11	2	3	18	19	10
B2	12	13	4	5	20	21
B3	23	14	15	6	7	22

Only 360 channels used to process the 2688 signals.

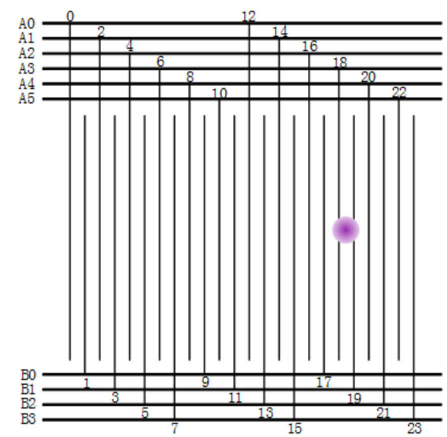
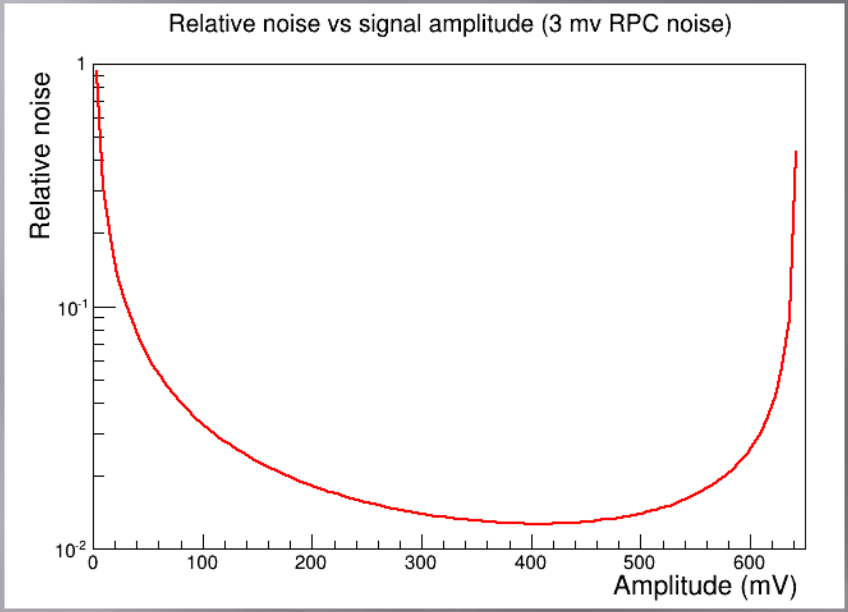


Fig. An example of fine-fine geometry

PAOLOZZI, Lorenzo (INFN)

The RPC space resolution with the charge centroid method

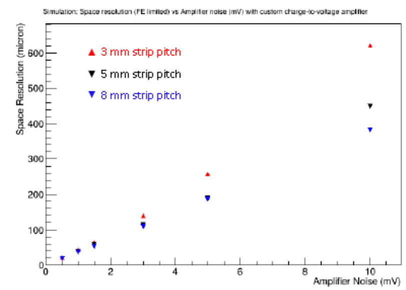


Simulation of response and optimization for space resolution measurements of a RPC detector

We carried out a simulation by generating Monte Carlo events according to data taken in a cosmic ray test (detector operated at 6.2 kV in Rome). Starting from the space charge model we measured a value of the parameter δ for the RPCs with 1.8 mm electrodes:

$$\delta \cong 4.0 \text{ mm}$$

The best resolution achievable with this model when limited by FE electronics is shown at different FE noise levels (of this FE) and with various strip pitch:

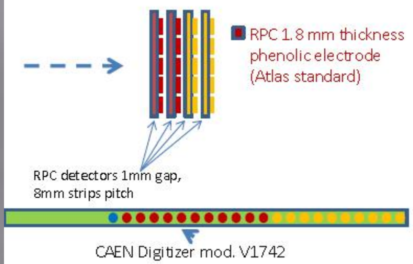


The actual noise of the amplifier was 3 mV RMS, that is ~2000 e⁻ RMS for our setup.

H8 Test Beam experimental setup

The RPC quadruplet has been tested at the H8 Muon Beam facility at CERN.

- Aim of this test was to evaluate the **spatial measurement capability for perpendicular tracks.**



Scheme of the experimental setup

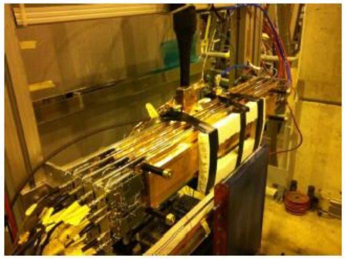
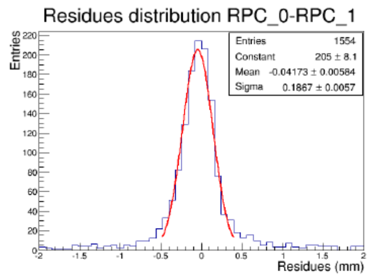


Photo of the experimental setup

All the waveforms were recorded by means of a 5 Gs/s, 32 channel digitizer model V1742
Trigger was given by a scintillator coincidence. Trigger area wider than detector area.

H8 Test Beam results



- Considering the resolution of the two detectors to be the same, the net resolution for the 1.8 mm electrodes RPC with 8 mm pitch is

$$\boldsymbol{\sigma_s = (132 \pm 5)\ \mu m}$$

From the simulation we expected the best achievable resolution to be

$$\sigma_{s,RPC\ FE} \cong 110\ \mu m$$

So it is possible to evaluate an upper limit for the intrinsic 1 mm gap RPC spatial measurement capability:

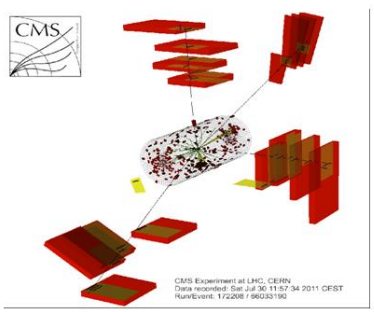
$$\sigma_{s,RPC\ intrinsic} = \sqrt{\sigma_s^2 - \sigma_{s,RPC\ FE}^2} \lesssim 70 - 80\ \mu m$$

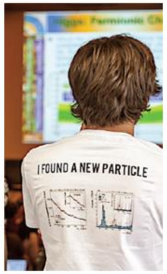
Plan of the talk

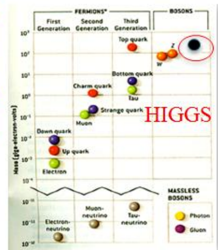
- Introduction
- Detector R&D
- Signal Readout
- Detector performance
- New deployments
- Applications
- Outlook

CMS RPC muon detector performance with 2010-2012 LHC data

July 4, 2012: Boson Higgs discovery

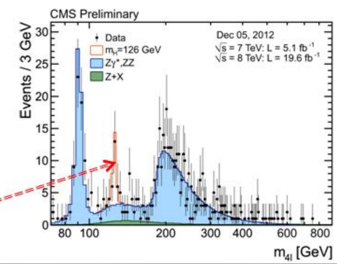






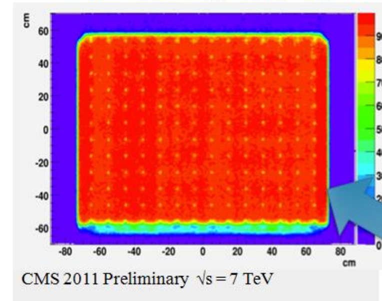
A nice CMS event with 4 muons
(RPC hits are in black)

Four-lepton mass spectrum:
clean signal peak at ~126 GeV

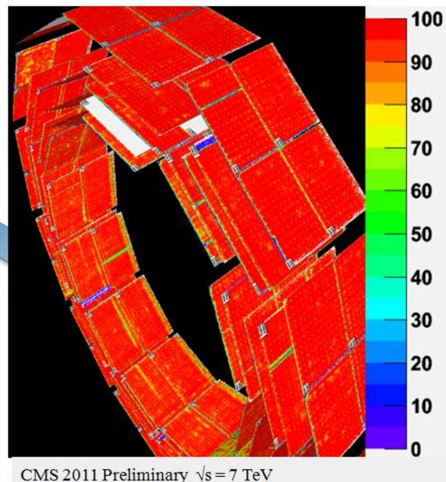


RPC muon radiography

2D chamber efficiency map



3D wheels efficiency view



Muon Radiography: the chamber efficiency can be studied in details, with a resolution of ≈ 1 cm^2. Spacers, border effects can be easily spotted. For few chambers, the stability in time of inefficient zones is under observation.
No degradation observed up to now.

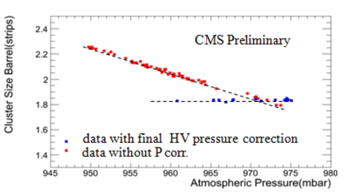
Working Point correction

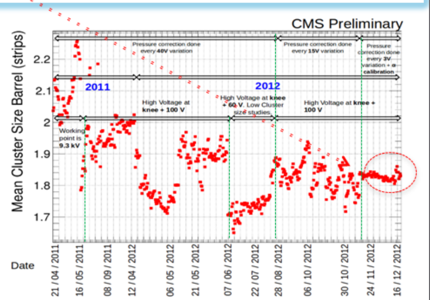
Fine tuning of the WP correction procedure to follow the atmospheric **pressure** variations:
Until August, 2012: WP corrected for pressure variations greater then ≈ 4 mbar, corresponding to a variation of the WP of 40 V.
From August to November, 2012: WP automatically corrected every variation of 15 V.
From November, 2012: WP automatically corrected every variation of 3 V and optimization of the formula using a factor correction (α = 0.8).

$$HV_{app} = HV_{eff}\left(1-\alpha+\alpha\frac{P}{P_0}\right)$$

Finally, a very ..very stable system….

P_0 = 965 mbar
~5 mbar on P variation → ~40 V difference





Barrel average cluster size in 2011- 2012

CMS RPC **system was operating well during RUN1 (2010-12)** delivering good triggers and data for physics:

- The contribution to the **CMS downtime** was about 1.5%.
- At the end of RUN1, the **fraction of active channels** was about 97.5%. Most of inactive channels have been already recovered during LS1.

After 3 years of LHC running with increasing instantaneous luminosity and 6 years from the end of RPC construction, the **detector performance** is within CMS specifications and stable with no degradation observed:

- **Average efficiency** was found to be about 95%.
- **Average cluster size** was ≈ 1.8 strips
- **Intrinsic noise** was ≈ 0.1 Hz/cm^2

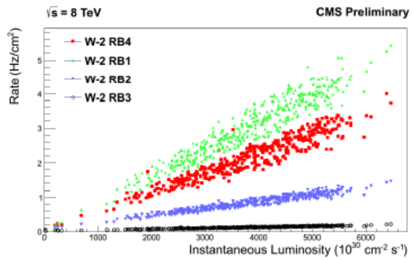
From the measured background: no significant issues were found for running up to HL-LHC.

CONSTANTINI , Silvia (Ghent University)

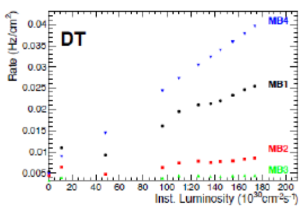
RPC Radiation background at the CMS experiment

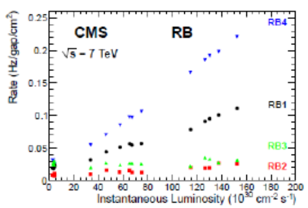
Barrel: rate as a function of R

- RPCs: Max rate is shown
- Barrel: highest rate in RB4 (return neutron flux) and RB1 (through calorimeter barrel/endcap gap)



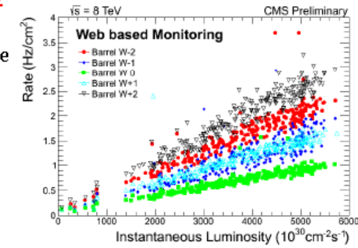
2010 data

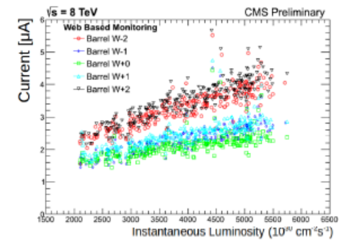


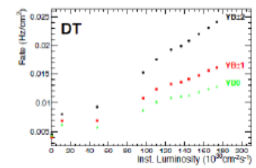


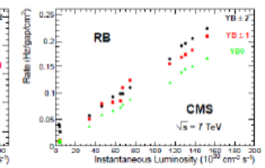
Barrel: rate as a function of z

- Highest rate in the external wheels W+2, W-2
- Larger rate on W+2 (with respect to negative side W-2) might be due to the presence of the CMS main shaft on the negative side
- RPCs: max rates are shown



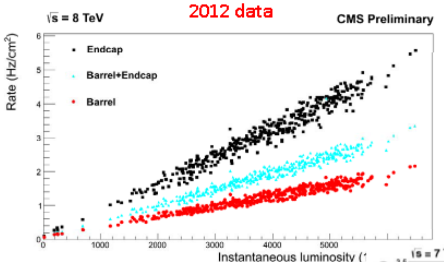


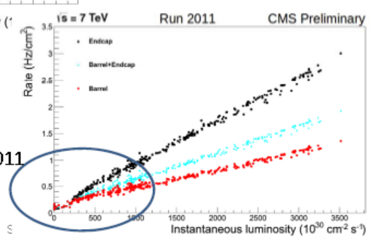




2010 data

Average detector rate



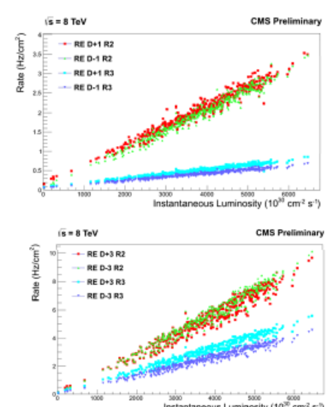


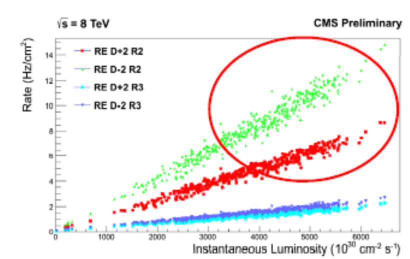
Due to Working Point change in 2011 (see G.Pugliese's talk)

RPC2014 23-28 February 2014 9

Endcap: RPCs

- Highest rate for internal Ring 2 of Disk 2
- Note z+/z- asymmetry. Observed in 2010 and 2011 data (partially due to CASTOR detector), still present in 2012 RE2/2 +/-



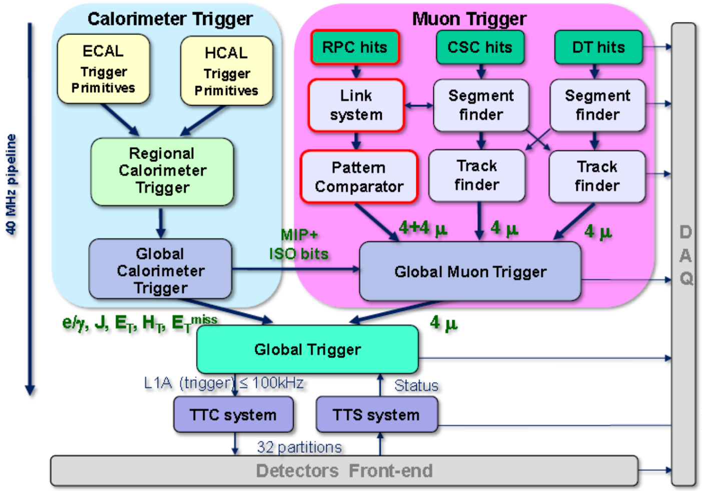


Silvia Costantini 12

KONECKI, Marcin (University of Warsaw)

CMS RPC trigger performance

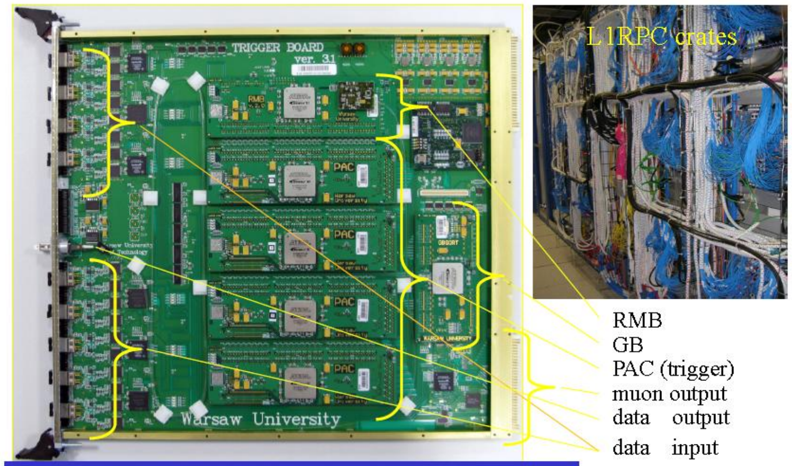
Level 1 trigger system



Trigger subsystems: identify, measure and sort the trigger objects

Global Trigger apply cuts: single or multi-objects, topological correlations

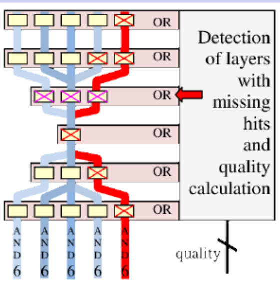
The heart of the system: Trigger Board



As the PAC algorithm is implemented in the reprogrammable FPGAs – Altera Stratix 2, it can be easily changed, to adapt to different requirements and running conditions.

Trigger Algorithm: Pattern Comparator (PAC)

- **The chamber signals (fired strips) are compared with the predefined set of patterns every 25 ns (BX)**
- Each pattern has assigned a transverse momentum (p_T) and sign (depending on the track banding by the magnetic filed).

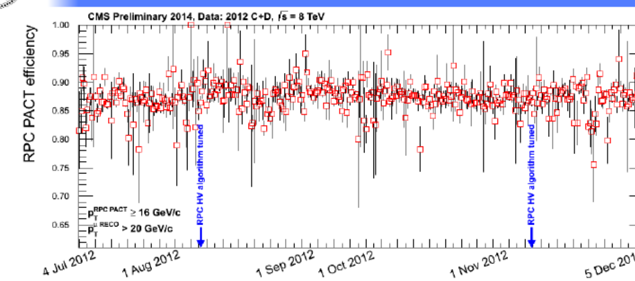


A pattern is a set of AND gates connected to selected strips

- A candidate is produced even though not all layers have hits. The minimum required number of fired layers is 3 (out of 3, 4, 5 or 6 layers available – depending on a detector region).
- In this way the trigger efficiency does not suffer from the limited geometrical acceptance and inefficiency of the chambers.
- The number of fired planes defines the candidate quality. The quality is used for the candidates sorting and "ghost busting" (cancellation of duplicated candidates).
- The patterns are generated based on the simulated muon track. Advanced algorithms are used to create the patterns from the simulated chamber hits, assign the p_T and then select optimal set of patterns.

The goal is to achieve best possible trigger efficiency and purity with a patterns set that can be fit into the PAC FPGAs.

RPC stability - efficiency

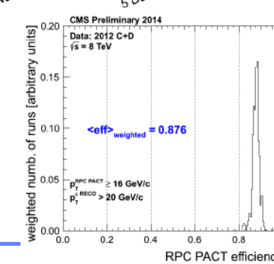


Upper plot: Efficiency as a function of time (low stat. runs excluded)

Right plot: RPC PACT efficiency distribution. Efficiency is weighted by run statistics and normalised to 1.

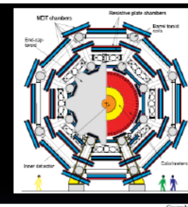
Select events with trigger other than only muon (L1, HLT)
Offline muon required ("tight", p_T^{RECO}>20 GeV, |η|<1.6, 2 stations)
Check if Level-1 PACT candidate present (p_T^{L1} > 16 GeV),
RPC candidate matched to offline muon by ΔR.
Presented efficiency is relative to good offline muons.

RPC PACT efficiency - stable in time



Performance and operations of the ATLAS RPC system in LHC Run-1

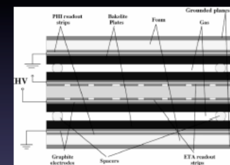
The ATLAS RPC System



3 concentric double RPC layers in the barrel region at radius ~7m to ~10m, operating in a toroidal magnetic field of approximately 0.5 T

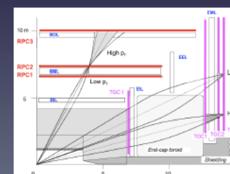
Main detector features:

- 2mm gaps using a mixture of $C_2H_2F_4$: i-C_4H_{10} : SF_6 (94.7 : 5.0 : 0.3)% operated in avalanche mode at 4.8 kV/mm with automatic T,p correction
- readout panels with strips 2.3-3.5 cm wide



About 3600 gas volumes in total, covering an area of 3650m², with 370k readout channels

Both polar (η) and azimuthal (ϕ) coordinate is measured from each gap



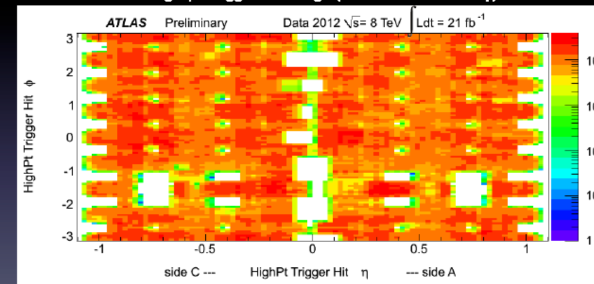
Exclusive LVL1 muon trigger for the barrel region and measurement of the track coordinate in the non-bending plane

RPC performance during 2012

Data taking very stable:

- good data quality fraction: ~~99.8%~~
- fraction of active readout channels: ~97%
  dead channels due to disabled trigger towers, gaps off or dead front-end channels

High-pt trigger coverage (2012 full luminosity)



Spatial coincidence between η and ϕ RPC pivot strips generating a High Pt trigger
The empty regions are due to not instrumented areas needed for services, toroid support feet and toroid coils

5

Background rates from 2012 data

Measured rate (Hz/cm²) at L=0.7*10³⁴ cm⁻² s⁻¹
extrapolated at L=1*10³⁴ cm⁻² s⁻¹
including a 1.6 factor for the E_{cm} increase

ATLAS RPC BM extrapolated average rate density — ATLAS *preliminary*
RPC unit Id. along Z direction

Sector Φ Id.	-7	-6.2	-6.1	-5	-4	-3.2	-3.1	-2.2	-2.1	-1.2	-1.1	01.01	01.02	02.01	02.02	03.01	03.02	4	5	06.01	06.02	7	Average (Hz/cm²)
01.01	40	42	37	36	29	19	14	17	13		9	8	9	14	15	16	18	26	36	34	36	30	23
01.02		38	35	38	28	21	16	18	16		10	9	10	15	17	17	19	28	40	35	39	38	24
2		16	26	24	18	14	12	10	9	7	7	6	7	9	10	13	12	18	26	25	21		15
03.01		37	37	38	26	18	16	15	14	9	9	9	10	16	16	16	17	26	38	34	36		23
03.02		38	36	39	27	19	16	18	15	11	10	10	9	16	17	19	19	26	38	33	37		23
4		14	23	23	20	14	12	9	10	7	7	6	7	10	10	12	14	20	24	23	20		15
05.01	35	27	27	32	21	13	13	16	15	9	9	9	10	15	20	13	15	22	31	24	24	27	19
05.02		29	29	28	18	14	15	16	16	10	8	9	10	14	16	13	16	21	29	32	32		19
6		16	24	25	19	13	12	11	11	8	7	6	8	10	10	12	14	21	24	26	22		15
07.01	34	37	34	35	25	21	17	16	15		10	10		15	18	16	20	24	35	34	37	32	24
07.02		40	33	30	16	18	14	16	13		10	10		13	16	15	20	15	39	35	32	36	21
8		15	25	24	20	13	11	10	9	7	7	6	7	8	9	11	14	20	24	24	22		15
09.01	28	39	32	37	26	20	15	17	14		7	9		13	16	16	18	25	35	34	36	28	23
09.02		40	33	35	25	19	14	14	13		8	10		13	14	13	18	24	35	32	35		22
10		16	26	26	18	11	11	9	9	6	6	5	7	9	9	10	11	18	24	25	23		14
11.01	29	37	31	30	20	14	11	12	10		6	5		10	11	12	13	19	29	28	33	22	18
11.02		25	23	20	14	11	9	7	7		5	5		7	8	8	10	13	19	21	23	32	13
12						14	13	10	9	6	5	5	6	9	11	13	14						9
13.01	40	37	34	30		17	13	12	11	6	6	6	7	11	12	11	16		30	33	37	30	19
13.02		37	33	28		14	12	13	11	6	7	7	7	12	13	12	15		27	29	35	31	18
14						15	18	10	8	6	5	5	6	8	10	17	15						10
15.01	25	23	25	19	14	11	9	9	7		5	5		7	8	10	12	14	19	22	23	24	13
15.02	34	24	21	31	20	16	12	13	10		6	6		10	13	14	15	20	31	24	27		18
16		16	27	27	21	13	11	8	9	8	7	7	7	9	8	11	13	21	26	26	21		15
Average (Hz/cm²)	34	25	29	29	21	15	13	12	11	7	7	7	8	11	12	13	15	21	29	28	28	29	17

Ageing qualification was done at 100 Hz/cm2 for 10 years of LHC running

A safety factor 5 was included wrt the expected max rate of 20 Hz/cm²

At large |η| the rates are above the expectations and will exceed the 100 Hz/cm² in phase-2

(see G.Aielli presentation for proposals for phase-2)

12

Conclusions

Results from Run-1

- Very stable and effective running for the ATLAS RPC system
  Definitely Run-1 has been very successful (not only for the RPCs …)
- Thanks to its redundancy the detector/trigger has reached its design performance (though at a lower luminosity) despite a few technical issues occurred during Run-1
- The measured background rate is higher than predicted
  Extrapolations to higher luminosity indicate that the maximum rate considered in the ageing qualification tests could be reached at large |η| already in phase-1

Preparation for Run-2

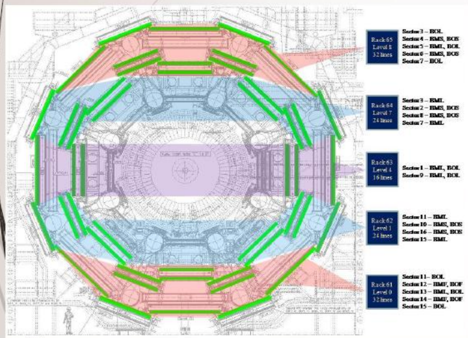
- In the current shutdown an intense consolidation work is ongoing to preserve the detector performance
- New RPC chambers installed in LS1 will increase already in the next data taking the coverage of the barrel trigger by 3.8%

19

ATLAS RPCs gas system maintenance and improvement

2

ATLAS RPCs Gas System Overview



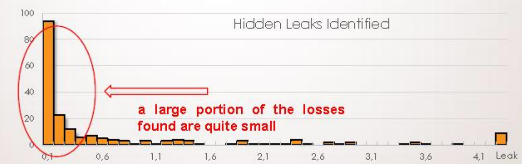
- **Gas mixture:** $C_2H_2F_4$(94.7%) : iso-C_4H_{10} (5%) : SF_6 (0.3%)
- **Total Gas Volume: 13490.3 l**
- **Number of Gas Volumes: 3592**
- **Gas circulates in a closed loop distributed by 5 gas racks in 5 height zones**

Authors: Enrico Pastori INFN Roma Tor Vergata

5

Gas Leaks

- In 2012 Run the RPCs had about 700 l/h of gas leak
- Since we plan to triple the current gas flow (according to the project) we did a test in Rack 65 following to this the losses increased only up 1000l/h
- In 2013 a big campaign of leak searching was done in the whole system
- Only about half of the gas loss was associated with already known leaking gap
- Almost all the gap leaking was found with some broken gas inlet



Flow sensors

- New sensors based on MEMS technology allow the widespread use even in large experiments at an affordable cost.
- Several manufacturers provide flow sensors based on MEMS with different properties
- we have chosen to test those best suited to our system:

13

OMRON D6F-P

Honeywell AWM9000

20

Conclusions:

- We understand the causes and identified precisely all the leaking gap.
- New repair methods have been developed to reach even the most inaccessible places.
- One volume of gas exchange per hour (the project value) and the proper gas distribution is sufficient to ensure a safe detector operation even for the future LHC foresees luminosity.
- Capillary network of gas flow sensors will be implemented for early gas leaks detection.

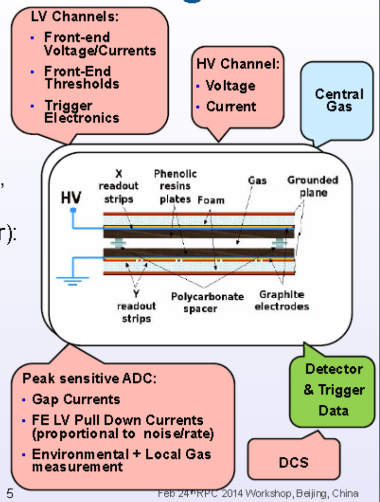
Authors: Enrico Pastori INFN Roma Tor Vergata

POLONI, Alessandro (INFN)

Monitoring and Control System of the ATLAS RPCs for Run-2

ATLAS RPC Monitoring

- Detector Supplies:
  - Low Voltages (Front-End, FE-Thresholds, Trigger Electronics)
  - High Voltage (to the gas gaps)
- Gas System:
  - Mixture, flux (in/out-leaks), Relative-humidity, other properties.
- Environmental variables (on detector):
  - Temperature, Atm. Pressure
- Detector Output
  - Signals, Trigger Rates, Detector Currents, Low voltage consumptions
- Monitoring/Calibration
  - Rates and currents, calibrated vs luminosity, vs HV and environmental parameters
  - Studies performed Online/Offline

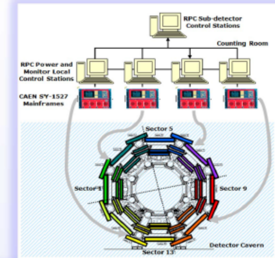


A. Polini 5 Feb 24th RPC 2014 Workshop, Beijing, China

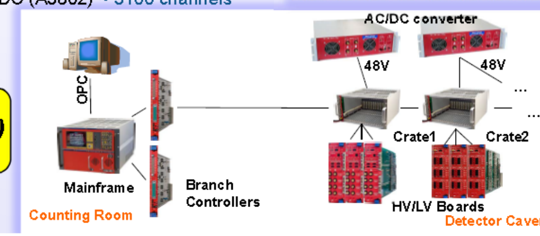
RPC Power and Control System

→ Commercial Solution: CAEN EASY system

- Scalable system with huge number of HV/LV channels to control
- 4 Mainframes (SY1527) + branch controller boards in counting room
- Boards can operate in radiation area and magnetic field (up to 2kG)
- Dedicated modules: Power (A3486); High Voltage (12 KV, A3512AP); Low Voltage (A3009, A3025B)
- ADC module (A3801) with mean and peak measurement (~6400 channels.)
- DAC 128-channel ADC (A3802) ~ 3100 channels



$$\frac{N_{ch}^{DAQ}}{N_{ch}^{DCS}} \approx O(100)$$



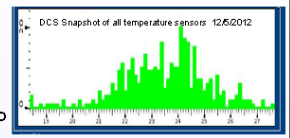
A. Polini

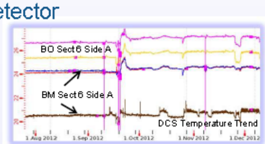
RPC HV Working Point Correction

- Due to other detector and infrastructure constrains the temperature of ATLAS Cavern was not uniform and above the expected 24 C in some areas (top sectors)
- RPC stability and efficiency depend on T and P

→ Local T/P correction to the HV applied to the detector

- $V_{applied} = V_{config} * \rho$ where $\rho = \rho_T \cdot \rho_P$
- $\rho_T = 1+\alpha_T \cdot [(T_0/T)-1]$
- $\rho_P = 1+\alpha_P \cdot [(P/P_0)-1]$
- RPC ~280 HV channels, ~ 350 T sensors
- HV settings checked every few minutes

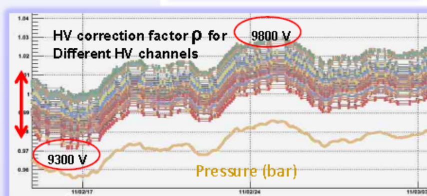




- Run-1 Settings:
  - V_{config} = 9600 (9500 V*)
  - P_0 = 0.970 bar
  - T_0 = 24° C
  - $\alpha_P = 0.8$; $\alpha_T = 0.5$

(* To limit chambers with T > 26°; ~ 5% of ch.)

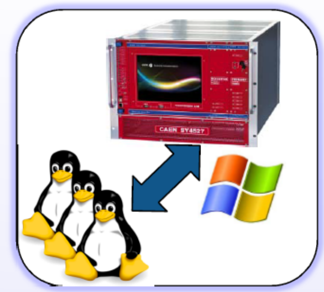
- Enabled and automatic for all of 2011 and 2012



A. Polini

DCS and Monitoring Upgrade for Run-2 (i)

- CAEN Mainframe upgrade SY-1527 → SY-4527 (New generation, higher speed due to improved handling of write/read commands, better long term mantainability, and support)
- New DCS Computers: from Windows SRV 2003 Linux SLC6 + VM (Win Srv 2008 R2)
- SCADA Program: PVSS 3.8 → WinCCOA 3.11
- Inclusion of additional chambers in lower sectors 12-13-14 (elevator and feet region: improved trigger coverage: 80→82%)



A. Polini 18 Feb 24th RPC 2014 Workshop, Beijing, China

DE GRUTTOLA, Daniele (INFN)

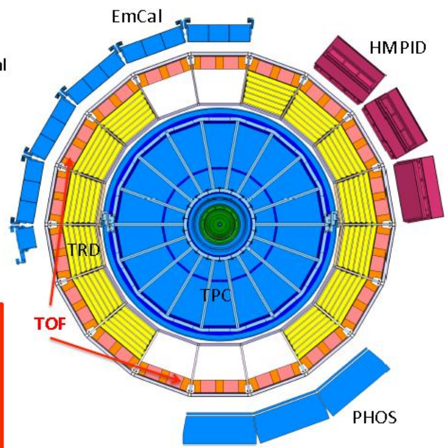
Particle IDentification with the ALICE Time-Of-Flight detector at the LHC

A large Ion Collider Experiment

The Time-Of-Flight detector: system overview

- active area 141 m^2
- radial distance 3.7 m
- pseudorapidity range $|\eta| < 0.9$, full azimuthal coverage $0 < \varphi < 2\pi$
- modular structure with 18 sectors in φ
- weight ~ 26 tons
- gas mixture $C_2H_2F_4/SF_6$ (93:7)
- granularity 2.5×3.5 cm^2
- 152928 readout channels
- made of 1593 glass MRPCs

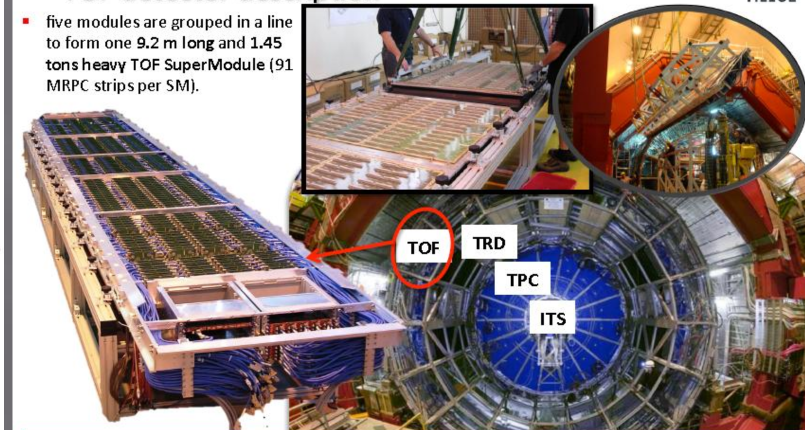
The MRPC was the only technology able to satisfy the three major requirements:
1. **extremely high time resolution**
2. **good efficiency**
3. **cost effectiveness**



A large Ion Collider Experiment

TOF detector description

- five modules are grouped in a line to form one **9.2 m long** and **1.45 tons heavy TOF SuperModule** (91 MRPC strips per SM).

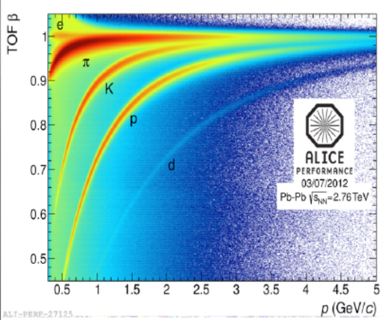


- The TOF is fully installed since April 2008; it has participated with full efficiency and acceptance coverage to all the ALICE data taking periods.

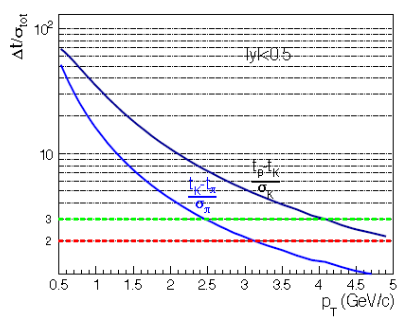
A large Ion Collider Experiment

TOF PID performance

Eur. Phys. J. Plus (2013) 128: 44



- Distribution of β as measured by TOF detector as a function of momentum for particles reaching the TOF in Pb-Pb interactions.



- Present separation power of the TOF for kaon-pion and proton-kaon as a function of p_T. **k/π separation up to 2.5 GeV/c and p/k up to 4 GeV/c.**

A large Ion Collider Experiment

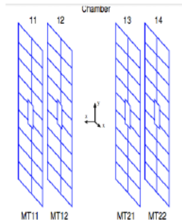
Conclusions

- the MRPC based ALICE TOF system is a very large and very high performance detector
- it has shown extremely high performance all over the first three years of data taking at the LHC. In spite of its complexity it has shown stable currents and rates behaved with no sign of ageing
- the TOF can provide 3σ *k/π* separation up to 2.5 GeV/c and *p/k* separation up to 4 GeV/c with full azimuthal coverage in the ALICE central barrel
- the TOF PID performance is instrumental for several physics analysis for all colliding systems and energies
- TOF reached (and even improved) the design goals

FONTANA, Mattia (INFN, Torino)

Performance of the ALICE muon trigger RPCs during LHC Run I

Muon Trigger system



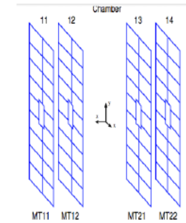
Setup

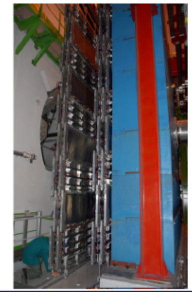
- 4 detection planes, arranged in two stations (16 and 17 m from the interaction point) of two planes each
- 18 RPCs per plane (72 in total)
- RPCs read on both sides, with orthogonal strips (8 real readout planes)
- each plane roughly $6.5 \times 5.5\,\mathrm{m}^2$, central hole of $1.2 \times 1.2\,\mathrm{m}^2$ for beam pipe and shielding structures
- strips of three different pitches (1, 2, 4 cm) and different lengths (projective geometry)

Main trigger functionalities

- Two different p_T cuts can be programmed and applied (e.g. 1 GeV/c and 2 GeV/c)
- Latency time $\sim$ 800ns
- 6 trigger signals sent to the ALICE Trigger Processor: single muon, unlike- and like-sign dimuon, high and low p_T

Muon Trigger system



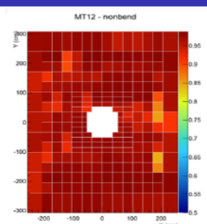


Resistive Plate Chambers

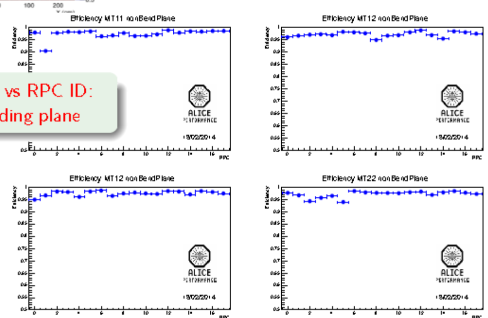
- Single 2 mm gap between low resistivity bakelite plates ($10^9 \div 10^{10}\,\Omega\,\mathrm{cm}$)
- Maxi-avalanche mode: gas mixture
  - $89.7\%\,C_2H_2F_4$
  - $10\%\,i-C_4H_{10}$
  - $0.3\%\,SF_6$

  Working HV: 10.2-10.4 kV
- 3 different shapes: area ranging from $(72 \times 223)\,\mathrm{cm}^2$ to $(76 \times 292)\,\mathrm{cm}^2$
- ADULT FEE allowing for two different operation modes.
  - FEE threshold = 7 mV ($\sim$2.5 Me)

Efficiency



- RPC efficiency is measured by exploiting the redundancy of the trigger algorithm (3/4 condition)
- All RPC efficiencies over 95% with very few exceptions



Efficiency vs RPC ID: non-bending plane

Conclusions

ALICE muon trigger RPC performance during 3 years of operation at the LHC, with integrated charge up to 7 $\frac{\mathrm{mC}}{\mathrm{cm}^2}$ (4 $\frac{\mathrm{mC}}{\mathrm{cm}^2}$ on average):

- Dark rate and dark current
  - Dark rate stable in time and $<0.1\ \frac{\mathrm{Hz}}{\mathrm{cm}^2}$
  - Dark current overall stable; slight increase during data taking and marked reduction after long HV-off periods with gas flowing
  - A few RPCs show a dark current increase, to be monitored
- Efficiency
  - Uniform and typically > 95 %
  - Stable in time throughout the whole running period
- Cluster size
  - $\sim$ 1.4 with 2 cm strips
  - Stable in time and in line with specifications

Outlook:

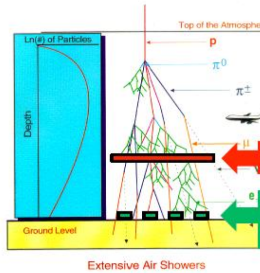
- Move from maxi-avalanche to genuine avalanche operation in order to cope with Run III running conditions

  $\hookrightarrow$ B. Joly's talk in the "RPC electronics" session (Wed. afternoon)

IUPPA, Roberto (INFN, Tor-Vergata)

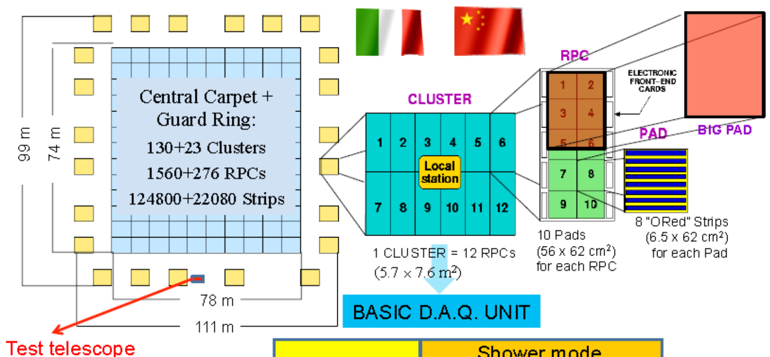
MEASUREMENT OF THE AIR SHOWER CORE PARTICLE DENSITY WITH ARGO-YBJ

ARGO is an unconventional EAS-array exploiting the full coverage approach at very high altitude to detect small air showers at an energy threshold of a few hundreds of GeV.

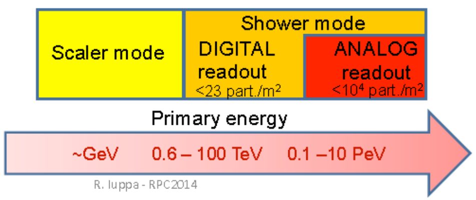


ARGO-YBJ — RPC technology — 1-technology experiment

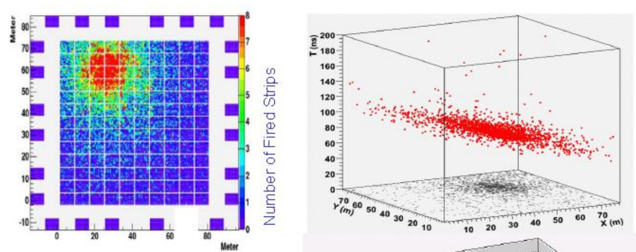
conventional EAS-array — 90 km Northward from Lhasa (Tibet) 4300 m above the sea level ~ 600 g/cm^2

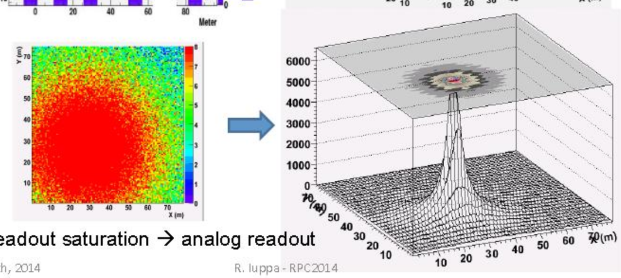


large area:
5600+1100=6700 m^2
92% active surface



Unprecedented detail in shower imaging.





Digital readout saturation → analog readout

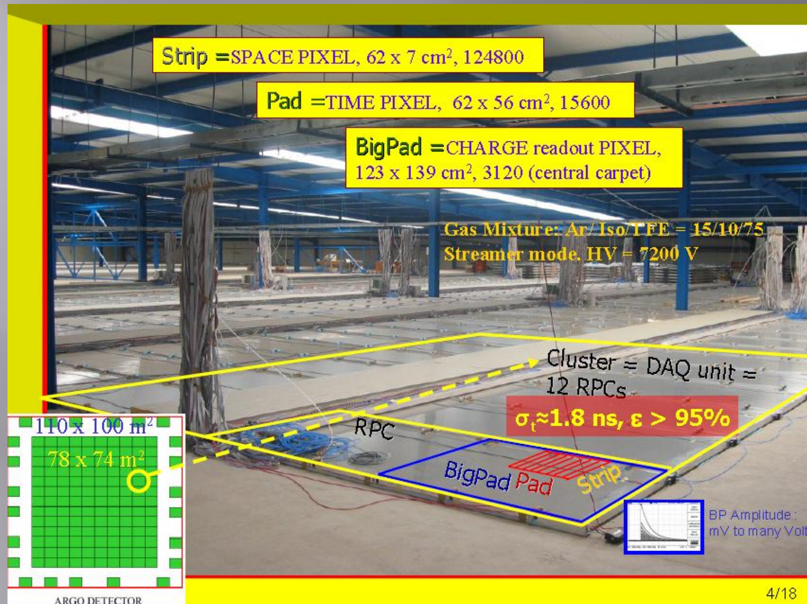
Conclusions

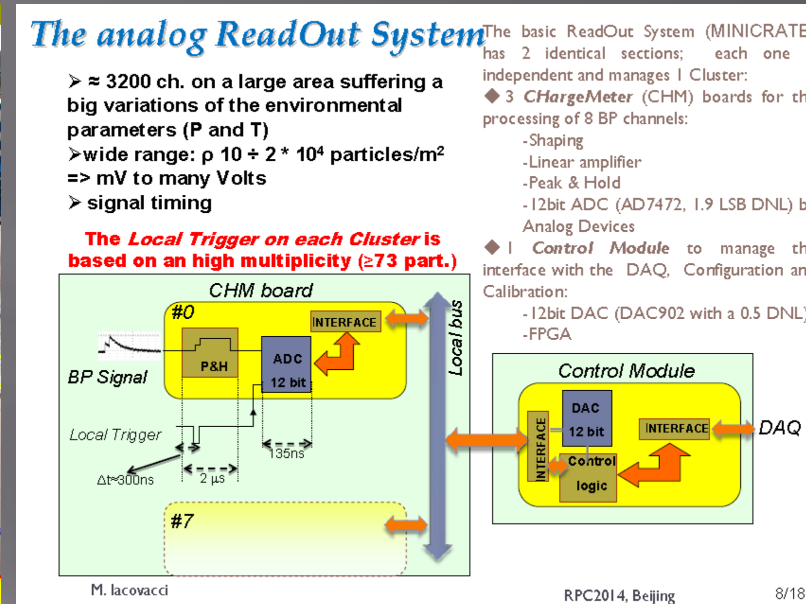
- The ARGO-YBJ experiment started collecting data in shower mode since November 2007.
- **The analog signal readout is operated since December 2009.**
- *Almost 5 10^{11}* events were recorded so far in digital mode.
- The operating conditions of the RPC carpet are continuously monitored by the DCS. The angular resolution and the efficiency keep being monitored with a test telescope realized on purpose. Important numbers:
  - Running time >90%
  - Duty cycle >86% (dead time <4%)
  - Intrisic trigger rate variations: 0.5%
  - Time resolution 1.5-2.0 ns
  - Efficiency always >96%

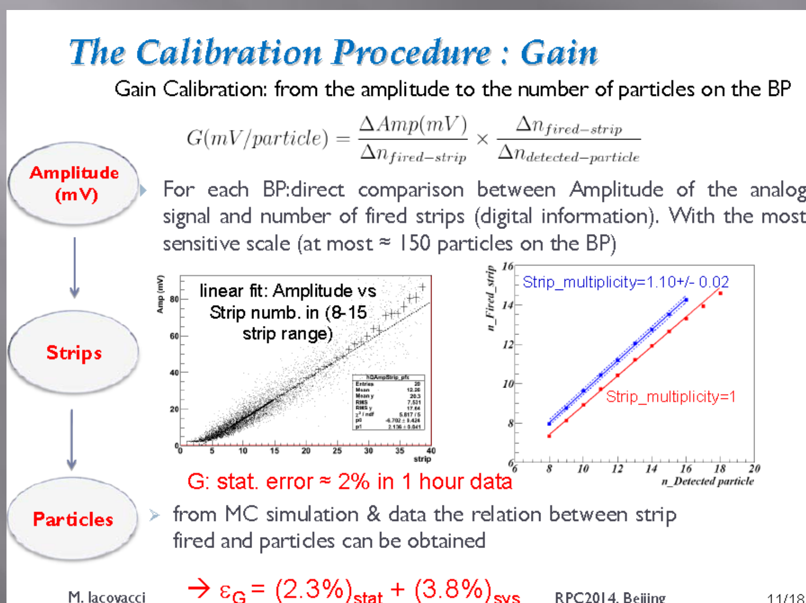
  All that in Tibet, *without permanent scientific staff* in situ. *The detector is only minimally protected against environment abrupt changes occurring at Yangbajing*.
- Many scientific results were obtained in particle and CR physics, as well as in TeV gamma-ray astronomy.
- **Thanks to the analog readout exploited with full coverage and at high altitude, for the first time an air shower array succeeded in measuring the particle density at the shower core.**

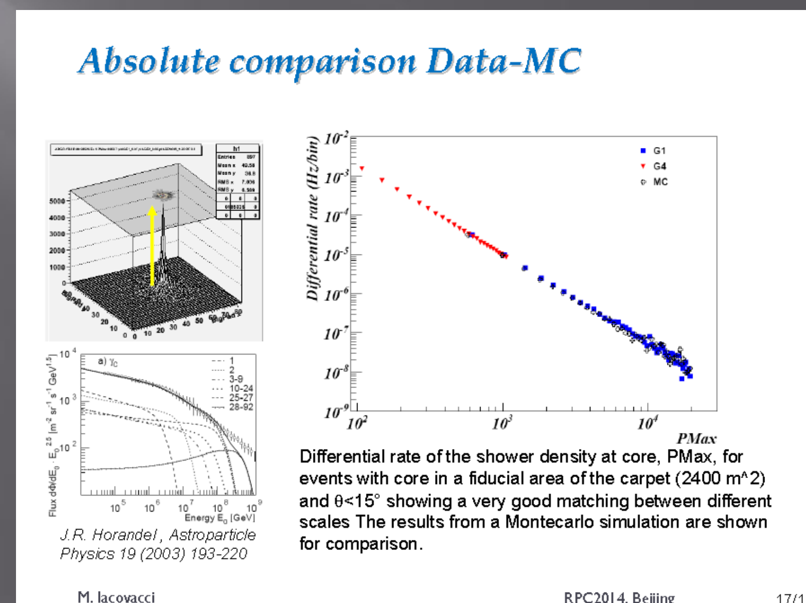
MICHELE, Iacovacc (Argo)

The analog RPC detector of the ARGO-YBJ experiment







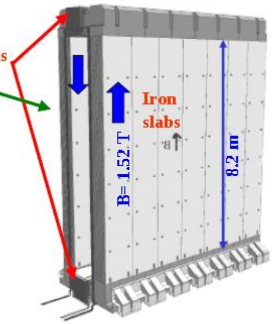


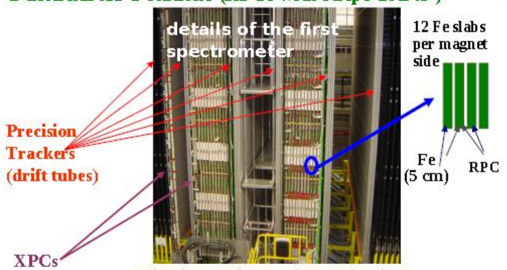
PAOLONI, Alessandro (INFN, LNF)

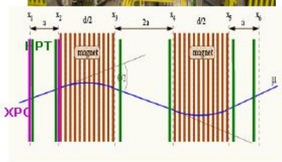
The OPERA RPC system

The OPERA magnetic spectrometer

Each spectrometer is composed by:
1 dipolar magnet (1.52 T)
22 RPC layers as inner tracker inside magnetized iron
6 drift tubes Precision Tracker stations (PT)
2 external XPC stations (RPCs with strips at ±43°)







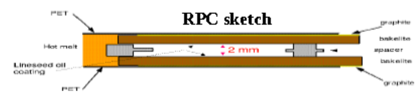
Charm bkg rejection in ν_μ CC events
Muon identification (with TT) >95%
$\Delta p/p$ < 20% for p<30 GeV
Charge misidentification < 0.3%

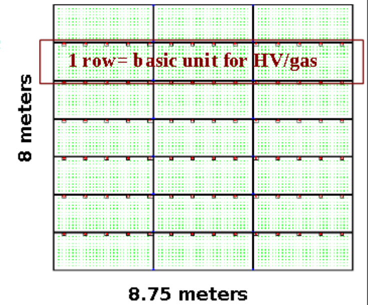
OPERA RPCs

Located in 2 cm gaps between iron slabs:
- Track reconstruction inside magnet
- Shower leakage measurement
- Trigger & Timing for the drift tubes

1 layer = 21 RPCs of size (2.9*1.1) m²
1 spectrometer = 504 RPCs/XPCs

- High resistivity bakelite electrodes (low rate expected): $\rho > 5 \cdot 10^{11}\ \Omega$ cm @20°C
- Special curved contour chambers
- Streamer mode operation (large signals)
- Read-out by means of ~8 m strips with 2.6 (3.5) cm pitch for bending (orthogonal) view

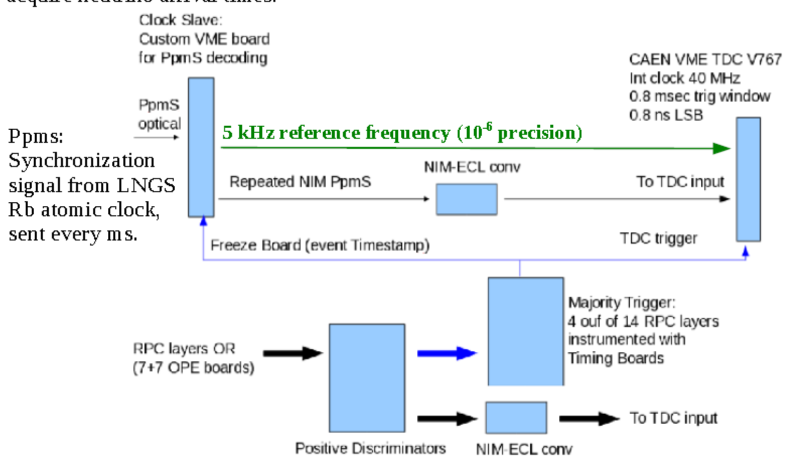




Total surface of the system ~ 3200 m²
Number of digital electronics channels ~ 28000
Streamer operation with $Ar/C_2H_2F_4/isoC_4H_{10}/SF_6$=75.4/20/4/0.6 (5 refills/day, open-flow system).
See JINST4 (2009) P04018 for Front-End discriminators and DAQ.

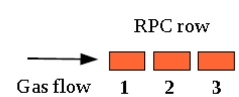
Neutrino velocity measurement results (Bunched Beam 2012)

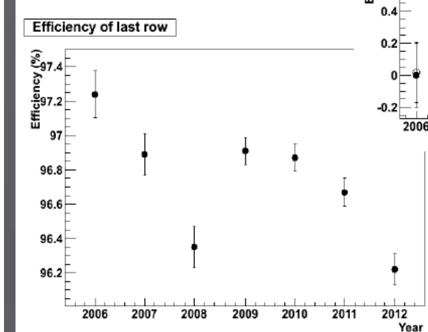
The neutrino velocity was re-measured in 2012 with a dedicated run in Bunched Beam mode (JHEP01 (2013) 153).
A new set-up, based on RPCs, was put into operation in parallel to OPERA DAQ to acquire neutrino arrival times.

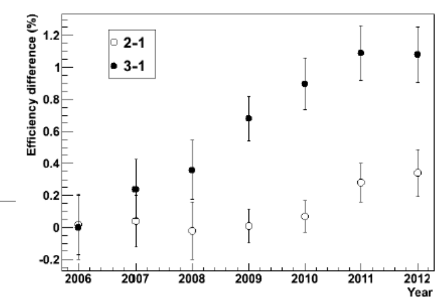


OPERA RPC aging 2: drying of bakelite electrodes

Single gas system for both spectrometer (bakelite) and VETO (glass) RPCs → dry mixture







1-2% efficiency loss due to bakelite drying

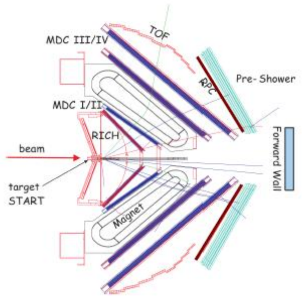
KORNAKOV, Georgy (HADES RPC Group)

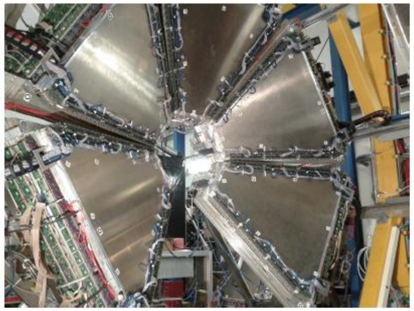
Time of flight measurement in heavy ion collisions with the HADES RPC TOF Wall

The inner Time of Flight Wall of the HADES spectrometer

HADES = High-acceptance dielectron spectrometer (GSI, Darmstadt, Germany)

Eur.Phys.J.A41:243-277,2009



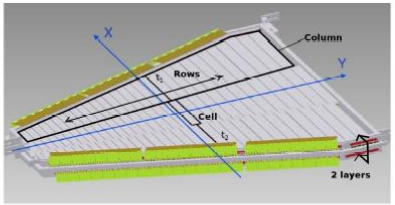


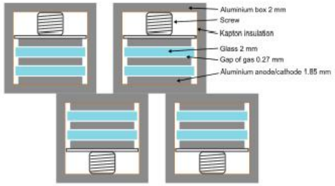
6 equal sectors or sextants cover about 8 m² at the inner part of the spectrometer.

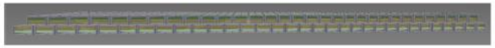
The RPC detector is placed after the tracking system (MDC & magnet) and in front of the Pre-shower detector. Particles path from target is about 2300 mm.

Georgy Kornakov, XII workshop on Resistive Plate Chambers, Beijing, 2014 2

Internal structure of the detector







Nucl.Instrum.Meth.A602:687-690,2009.
Nucl.Instrum.Meth.A602:691-695,2009
doi:10.1016/j.nima.2010.08.033
IEEE Trans.Nucl.Sci. 57 (2010) 2848 - 2856
IEEE Trans.Nucl.Sci. 55 (2008) 59-66

- 3 columns with 31 rows of cells.
- 2 partially overlapped layers.
- 1116 strip-like, 4-gap (0.27 mm), symmetric, timing RPCs ("cells"). Aluminium and Glass. Read out at both sides: 2232 channels.
- Each cell is individually electrically shielded for robust multihit performance.
- Sizes: cell width ranges from 22 to 50 and the length ranges from 120 to 520 mm.

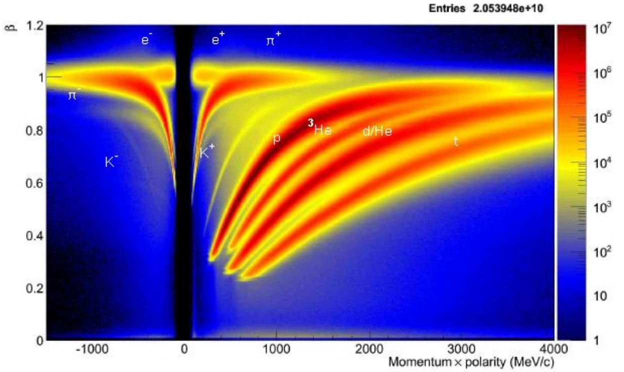
- Operation voltage: 5500V
- Gas mixture 90% $C_2H_2F_4$ and 10% SF_6

Georgy Kornakov, XII workshop on Resistive Plate Chambers, Beijing, 2014 3

Calibration and synchronization methods and strategy

PID plot of Au+Au collisions @ 1.23 AGeV

Additional selection of track quality, event quality and trigger were used.



The presence of kaons testifies a very good performance in high multiplicity environment

Georgy Kornakov, XII workshop on Resistive Plate Chambers, Beijing, 2014 15

Summary

- The operation of the HADES RPC ToF Wall was stable during the beam time. Operation was done with constant settings.

- The performance study shows an overall efficiency of 97% and mean time resolution over 1116 cells of 69 ps sigma, and 76 ps for MIPS.
- High performance of the detector in high multiplicity environments: occupancies up to 30%.
- Track resolution measured for electrons: 113 ps

- The measured times were calibrated and synchronised in order to provide the best identification capabilities for analysis. Only one set of parameters is needed for the whole beam time.

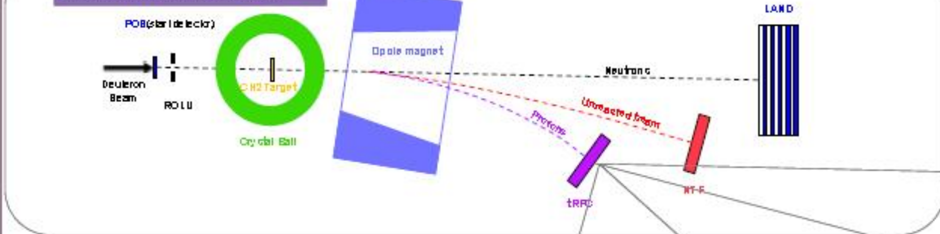
- An independent method for direct intrinsic efficiency estimation was developed. Its main goal is to work with full particle reconstruction and selection, and without external references. Results between both methods are compatible.

Georgy Kornakov, XII workshop on Resistive Plate Chambers, Beijing, 2014 25

MACHADO, Jorge (University of Lisbon)

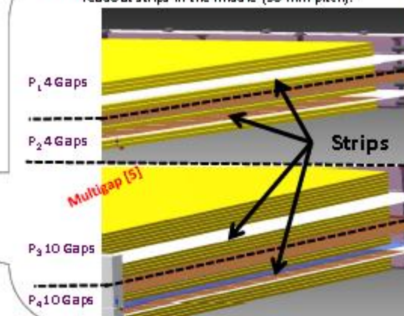
Performance of timing RPCs with relativistic protons from 200 to 800 MeV

Experimental setup

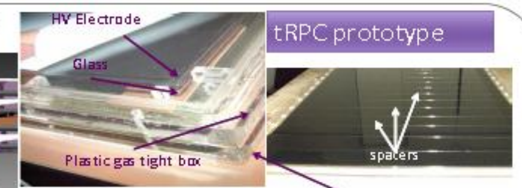


A deuterium beam in the energy range from 200 to 800 MeV is used to produce quasi-monoenergetic neutrons and protons beams. Neutrons continue in the forward direction, while the protons are bent using a strong magnetic field towards the protons detectors including the tRPC prototype.

4 RPC planes, P_i, each built from two modules with 15 readout strips in the middle (30 mm pitch).



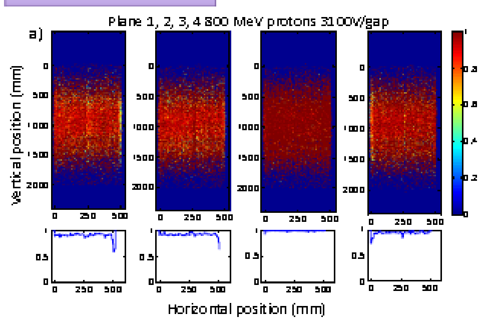
tRPC prototype



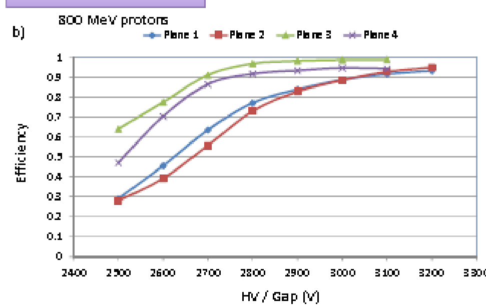
The RPC prototype was built based on modules. A module contains the glass and HV electrodes enclosed in a plastic gas tight box with feed-through for gas and High Voltage.

2.85 mm soda-lime glass electrodes (~10^{12} Ωcm) and 300 µm gap width in multigap [5] construction operated in 90% $C_2H_2F_4$ 10% SF_6 with a flow of 15 cm³/min/module

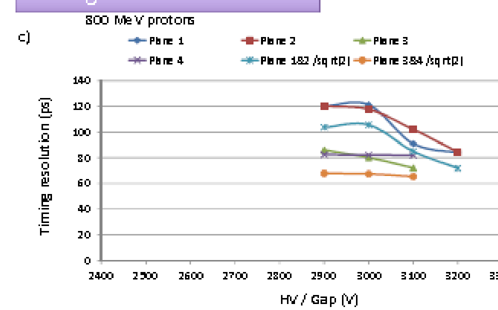
Efficiency Vs X, Y



Efficiency Vs HV

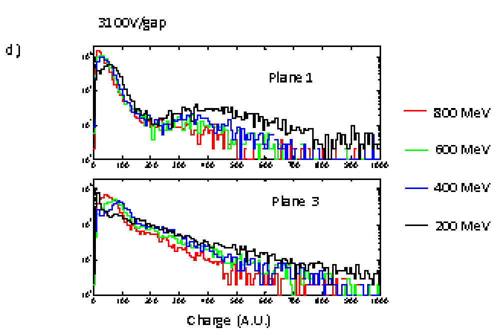


Timing resolution Vs HV

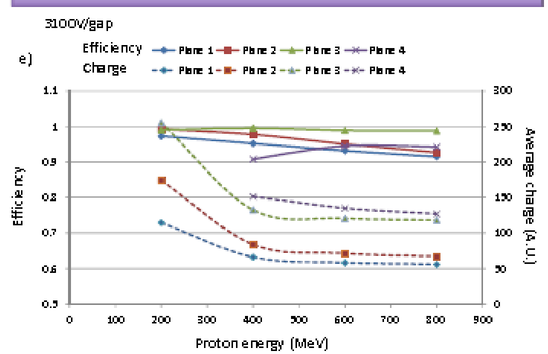


The detection efficiency is shown in figures a) and b) as a function of X and Y position and HV respectively. All four planes exhibits an homogenous efficiency without noticeable dependence with position. Planes P_1 and P_2 (with four gaps) and P_3 and P_4 (with ten gaps) show similar behaviour as a function of HV reaching efficiencies close to 1 above 2800V/gap for the 10 gaps planes, while the 4 gap planes reach this efficiency for 3200V/gap or above. Figure c) shows the timing resolution as a function of HV (lack of points below 2900V/gap is due to the low statistic available). The optimal timing resolution is around 80 ps for all the planes without dependence with HV for the 10 gas planes and only reached at the maximum HV measured for the four gaps planes. At this level, the timing resolution starts to be influenced by the electronic readout chain resolution.

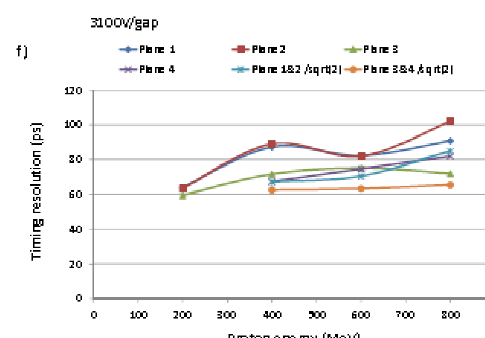
Pulse height spectrum



Efficiency & average charge Vs proton energy



Timing resolution Vs proton energy



BLANCO, A (LIP)

Performance of timing Resistive Plate Chambers with relativistic neutrons from 200Mev to 1500MeV

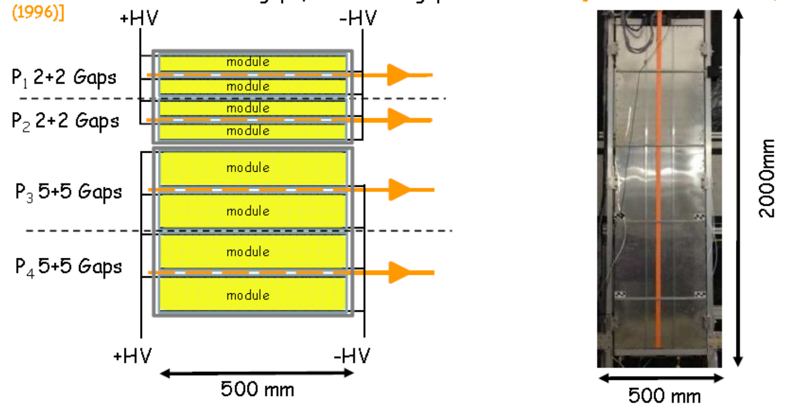
Outline

- Motivation: a **new neutron ToF detector NeuLAND** (New Large Area Neutron detector) for the **R³B collaboration** (Reactions with Relativistic Radioactive Beams) at GSI, Darmstadt, Germany.
- RPC **performance. Simulation** studies.
- **RPC prototype** and setup description at GSI where the beam was provided in experiment S406.
- Analysis:
  - **Neutron selection**
  - **Timing resolution**
- Conclusions

RPC2014 Workshop. 26-02-2014. Beijing A. Blanco 1

Setup. RPC prototype

4 RPC planes, P_i, each built from two modules with **15 readout strips** in the middle (**30 mm pitch**). Half of the layers are built from modules with 2 gaps, while the rest are built with 5 gaps, all in multigap construction [Nucl. Instr. Meth. A 374,132 (1996)]



Gas mixture 90 % $C_2H_2F_4$ and 10 % SF_6 @ 15 cm^3/min/module at a pressure slightly under atmospheric pressure to define correctly the gap width.

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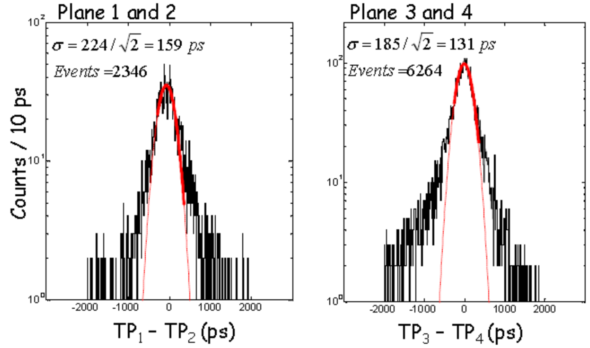
ANALISYS. nTOF -> $\sigma(T_{RPC\ neutron})$

The **RPC response to neutrons** can be evaluated by calculating the time difference between planes.



Relatively independent of energy

E (MeV)	$\sigma(TP_1 - TP_2)/sqrt(2)$ (ps)	$\sigma(TP_3 - TP_4)/sqrt(2)$ (ps)
300	150	143
500	178	138
800	176	148
1500	159	131

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Conclusions

A study, based on simulations, has been done to **optimize the design of a RPC for the detection of fast neutrons** showing that the RPC technology could be an attractive option

Based on this study a **RPC prototype has been built** and exposed to neutrons of various energies (300 MeV to 1500 MeV)

The **time of flight of neutrons** with energies between **300 and 1500 MeV** has been measured with a contribution of the RPC of around **140 ps independent of the energy.**

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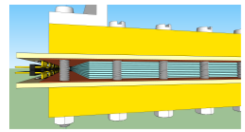
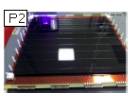
RPC test with heavy-ion beams

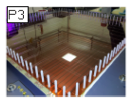
SIMON, Christian (Heidelberg University)

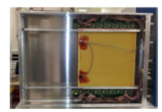
RPC Prototypes made in Heidelberg

- prototypes for different rate regions of the TOF wall
- fully differential multi-strip multi-gap RPCs
- HV +/- 11 kV; 8 gaps single stack, width 220 µm
- preamplifier cards (PADI) inside the gas volume, directly connected to the read-out electrodes
- HD-RPC-P2: 32 read-out electrodes, length 27 cm, pitch 1 cm, surface 864 cm², 0.7 mm low-resistive glass (10^{10} Ωcm)
- HD-RPC-P3: 56 read-out electrodes, length 53 cm, pitch 9.4 mm, surface: 2800 cm², 0.5 mm float glass (10^{12} Ωcm)
- gas mixture: 85 % $C_2H_2F_4$, 10 % SF_6 and 5 % C_4H_{10}



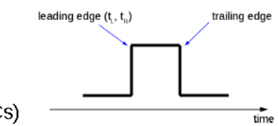


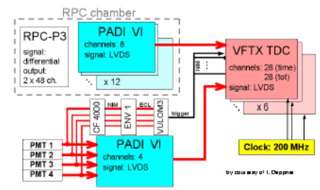


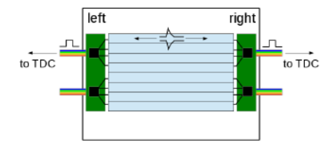


The RPC Read-Out Chain

- differential analog signals on the read-out strips are merged by subtraction, discriminated and converted to logical pulses (PADI chip)
- timing quantities encoded in logical pulses:
  - t_L, t_R (leading edge)
  - ToT (pulse width)
- digitization by time-to-digital converters (TDCs)
  - VFTX: FPGA-TDC, 10 ps single-board resolution



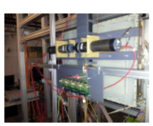


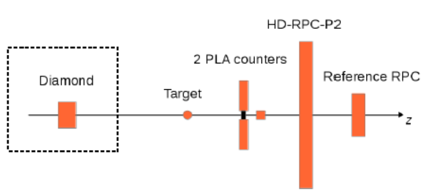


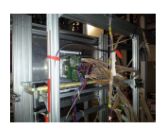
$t_{corr} = t_{TDC} + o_{global} + o_{event}(ToT, ToF, \ldots)$

GSI In-Beam Test Setup Fall 2012

- data acquisition in August, October and November 2012
- full-counter response study of the HD-RPC-P2 against a reference RPC built by the NIPNE group from Bucharest, Romania (72 read-out electrodes, surface 84 cm², equipped with PADI outside the gas volume)
- diamond beam particle counter as time reference upstream of the Pb target (**problem:** VFTX FPGA-TDC could not digest the MHz rates)
- plastic counters (as in the lab tests) were used as backup; meaningful results only for low particle fluxes between 40 Hz/cm² – 60 Hz/cm²

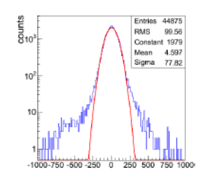


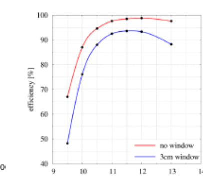




HD-RPC-P2 Response in Beam

- cluster matching after strip-wise global and event-based corrections and clustering on both HD-RPC-P2 and the reference RPC:
  - coincidence in both plastic counters
  - 1 (and only 1) cluster on the reference RPC
  - scan HD-RPC-P2 for matches (acceptance within a radius of 3 cm)
- system time resolution of **78 ps** between HD-RPC-P2 and the reference
- post-matching efficiency of **93.6 %**, pre-matching efficiency (acceptance radius disregarded) of 99 % (algorithms under development)
- promising results for the in-beam performance of the prototype





Plan of the talk

- Introduction
- Detector R&D
- Signal Readout
- Detector performance
- New deployments
- Applications
- Outlook

PARK, Sung Keun (KODEL)

Production and qualify Assurance for RPC gaps for RE4 Resistive Plate Chambers for future CMS Experiments

1. Production of the gaps at KODEL

For RE4, the facilities used for the previous RE1~3 RPC productions reinforced.

- ✓ Graphite coating table
- ✓ PET-film coating tool
- ✓ Gap-gluing tables and shelves
- ✓ Linseed-oiling tool
- ✓ HV-test facility
- ✓ Robot for leak and spacer tests

Graphite layer by a silkscreen method
- ✓ Thickness ~ 10 μm
- ✓ Surf. resistivity: 100 ~ 250 kΩ/□

PET film coating using EVA hotmelt
- ✓ PET film: 190 μm
- ✓ Hotmelt glue ~ 100 μm

RPC2014 2

Gap assembly

Multi-layered metric tables and shelves for the assembly and glue curing

Glue curing time : 24 hours

Glue : DP460, 3M production

Selection of spacers : 2 mm +/- 20 μm

Use spacer jigs for the location of spacers ~ Accuracy of positions ~ 1 mm

Linseed-oil coating tool
- ✓ Linseed oil + heptane (Ratio : 40 % + 60 %)
- ✓ Polymerization with air
- ✓ Rate : 60 ~ 100 liter/h/gap
- ✓ Period : 96 hours
- ✓ Humidity: ~ 35%

RPC2014 3

2. Criteria of QC test for gaps

1) Visual tests
- ✓ HPL (barcodes & visual conditions)
- ✓ Graphite (resistivity and visual inspections)
- ✓ PET coating (visual inspections)
- ✓ Bending of gap
- ✓ Gas pipes and HV & GND cables
- ✓ Gap barcode and etc…

Rejection rate: 7.8% at KODEL (mainly due to poor PET coating problem)

2) Leak & detached spacers
- ✓ Spacer test at ΔP = +20 hPa

  If Δ (ΔP) > 0.5 hPa → Pop spacers

Rejection rates at KODEL
- Due to detached spacers ~ 14.5%
- Gas leak ~ 1%

Leak limits for 600 s at +20 hPa to be certified	RE4-2 TW	RE4-2 TN	RE4-2 B	RE4-3 TW	RE4-3 TN	RE4-2 B
	0.2 hPa	0.3 hPa	0.4 hPa	0.3 hPa	0.4 hPa	0.5 hPa
Detached spacer allowed	No	No	1	No	No	1

RPC2014 4

Summary and Conclusion

Summary of Production Yields

Total numbers of HPL panels used (to be used) for RE4 RPCs ~ 1502 panels

Total number of QC-qualified gaps at KODEL = 614 gaps

269 gaps for RE4-3 RPCs + 345 gaps for RE4-2 RPCs

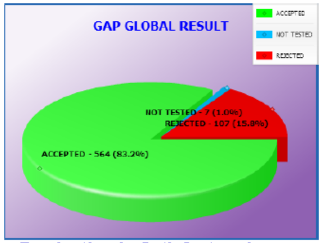
→ Rate producing QC gaps using given HPL panels at KODEL = 614 × 2 / 1502 = 0.818

Total number of gaps produced at KODEL = 678 gaps

→ Rate producing QC gaps out of produced gaps at KODEL = 614 / 678 = 0.906

Total number of QC-qualified gaps at assembly sites ~ 511 gaps

→ Rate of QC-qualification for the delivered gaps at assembly sites= ~ 511 / 678 = 0.832



Overall Rate of QC of Gap Production is Satisfactory !

RPC2014 19

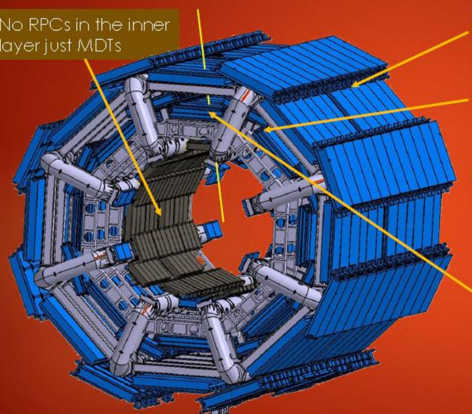
AIELLI, Giulio (INFN, Tor-Vergata)

High Luminosity (HL) LHC perspectives for the ATLAS RPC system

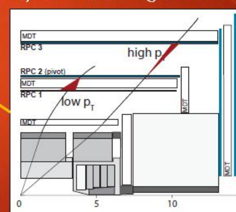
The ATLAS RPC Muon System today

2

No RPCs in the inner layer just MDTs



- OUTER LAYER for High pT trigger
  - One doublet chamber
- MIDDLE LAYER for Low pT trigger
  - Two doublet chambers
- IN TOTAL 6 independent layers measuring Eta and Phi



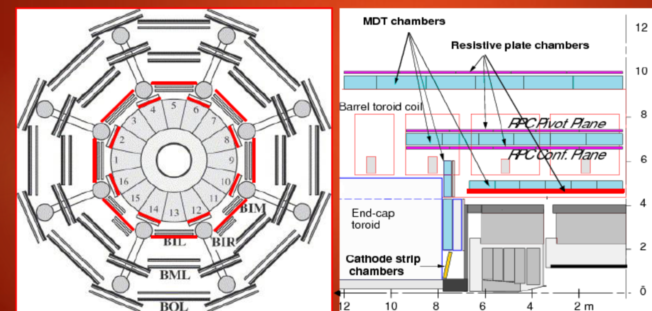
G. Aielli RPC 2014 3/17/2014

RPC upgrade proposal

6

increase the redundancy by adding the RPC inner layer

This idea was already considered in the original project of the barrel trigger detector, but at that time the need for the 3rd station was not stringent and it was canceled when a substantial downgrade was required to Atlas



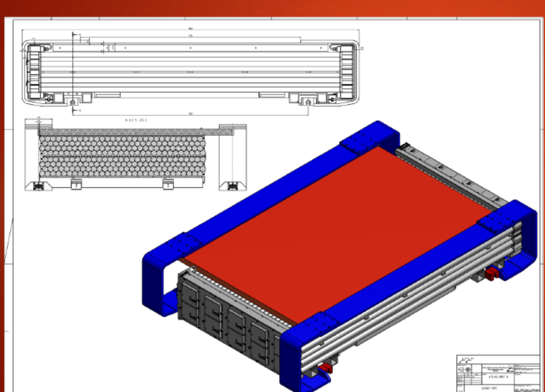
- 9 layers instead of 6
- 4 chambers instead of 3

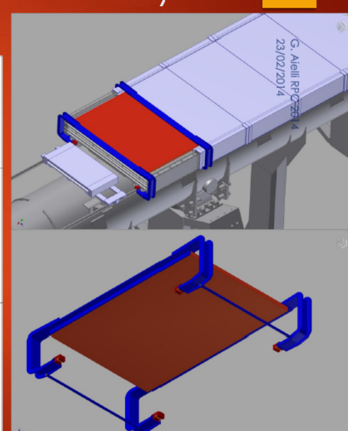
G. Aielli RPC 2014 23/02/2014

Mechanical solutions under study…

20

also for the BIS 7-8 (*see Hongye slides*)



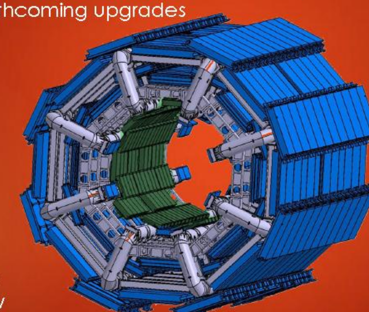


G. Aielli RPC 2014 23/02/2014

Conclusions

22

- The completion of the muon barrel trigger detector with a full set of BI RPCs is required to ensure a good LVL0/LVL1 performance through the forthcoming upgrades
- This new chambers will inherit the R&D effort being performed for the proposed BIS RPCs for the transition region.
- The present RPC chambers will also benefit from a new RO electronics



- Notwithstanding the fact that in Run 2 the RPCs will still be within the design safety factor, there will be the chance to understand if there is any critical area where the redundancy given by the BI chambers should be anticipated to Phase1

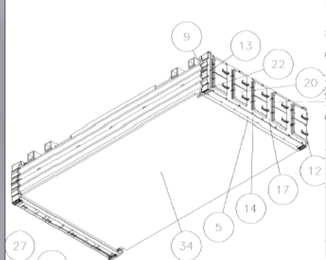
G. Aielli RPC 2014 23/02/2014

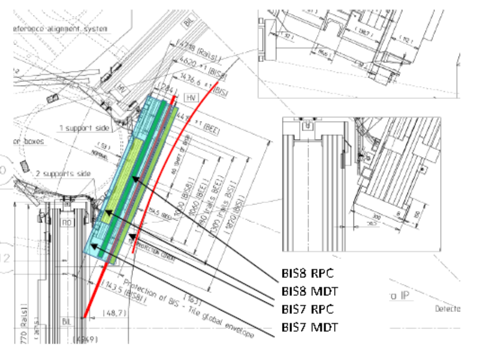
ATLAS Transition Region RPC Upgrade at Phase-1

SONG, Hongye (ATLAS)

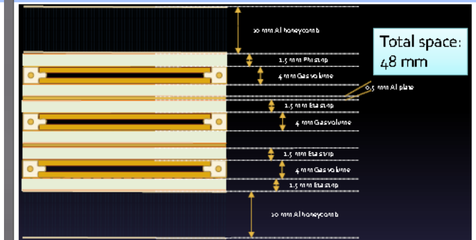
Mechanical Layout

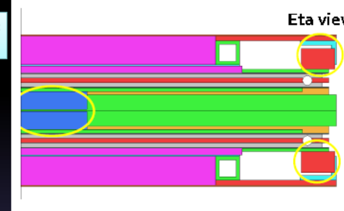
- Very Limited Space available: ~5cm requested
- Integration with BIS7 MDT detector
- BIS7: $1.7 \times 1.3 = 2.21 m^2$
- BIS8: $1.7 \times 0.5 = 0.85 m^2$

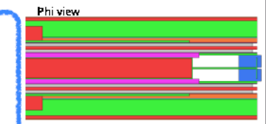




Chamber Design







Detector layout Options:

- 3-layer detector operated with a 2/3 majority ideal configuration
  - Possible local 5-10 ns coincidence→ high rejection of the noise
- thin gas gaps (1mm) equipped with a new front end electronics which will reduce the delivered charge and will improve the timing at the same time
- thinner electrode plates (about 1.2 mm)
- much thinner supports of higher mechanical quality
- Strip PHI: traditional (BME way), meantimer with double Eta FE, absent…

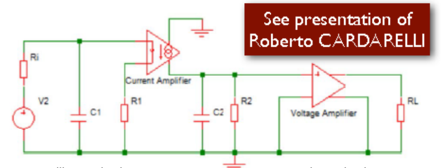
Chamber building blocks are the **SAME** as the BOE/BME system on production.

	#chambers	# layers	size eta	size phi	total gaps	total area
BIS7	16	3	1.3	1.7	48	106
BIS8	16	3	0.5	1.7	48	41
Totals					96	147

Front-end Electronics Design

A new front-end electronics has been designed based on the conceptual scheme below. This is explicitly designed to exploit the BJT transistor features for the fast pulses generated by detectors such as Diamonds and RPCs. This scheme has been implemented both with standard Silicon transistors and with the SiGe technology, which offers a better performance by more than an order of magnitude, in particular concerning the S/N and the switching speed of the order of 100 GHz.

See presentation of Roberto CARDARELLI



The conceptual design of the proposed 8 ch. FE chip, including both amplification and digitization

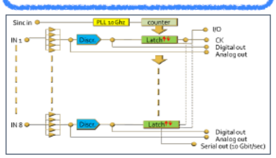
- Simple design allowed by the SiGe switching speed > 200 GHz
- Can be made compatible with NSW PAD

Silicon technology

Voltage supply	3–5 Volt
Sensitivity	2–4 mV/fC
Noise (independent from detector)	4000 e^- RMS
Input impedance	100–50 Ohm
B.W.	10–100 MHz
Power consumption	10 mW/ch
Rise time $\delta(t)$ input	300–600 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}

SiGe technology

Voltage supply	2–3 Volt
Sensitivity	2–6 mV/fC
Noise (independent from detector)	500 e^- RMS
Input impedance	50–200 Ohm
B.W.	30–100 MHz
Power consumption	2 mW/ch
Rise time $\delta(t)$ input	100–300 ps
Radiation hardness [4]	50 Mrad, 10^{15} n cm^{-2}



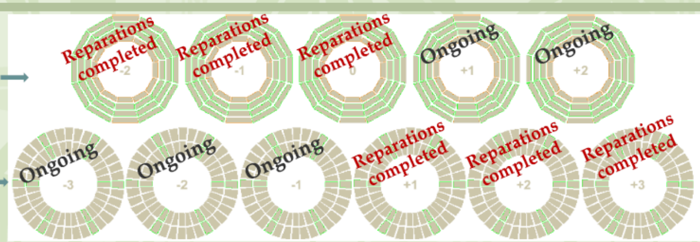
Conclusion

- ATLAS transition region (BIS7/8) RPC upgrade is a great opportunity to improve the technology of RPC and auxiliary electronics. The project also could encourage people, who are interested in hardware to participate in the RPC R&D.
- Still have some tough technical challenges:
  - Integration in an already existing system, exploiting the existing limited amount of space
  - Mechanical matching with the NSW design and alignment
  - Guarantee full efficiency and long operation with a 10 time higher cavern background, that is expected in Phase-2

CIMMINO, Anna (Ghent University)

CMS RPC Commissioning of the Existing Detector During the Long Shutdowns

HV & LV Interventions



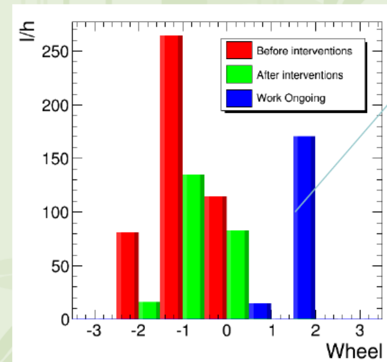
- 55% of the system accessed and reparations were completed. 1.11% of electronic channels have been recovered.

- High Voltage
  - The HV problems were mostly due to a broken tri-polar connector beyond the patch panel. Problems fixed by connector replacement or gap disconnection.
  - 0.24% of Electronic channels recovered.
- Low Voltage
  - 0.87% of the total electronic channels recovered

A. Cimmino – RPC 2014, Beijing 10

Gas Leak Reparation Campaign

Gas Leak Campaign Results for Barrel



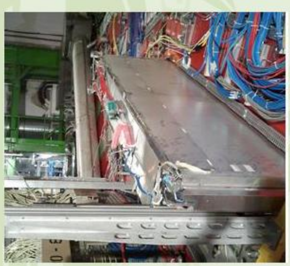
- Total 644l/h before interventions
- 3/5 Wheels are completed
- 2/5 Wheels have not yet been accessed
- We succeeded in reducing the gas leak of ~51%
- The Majority of the leaks are due to broken T-connectors

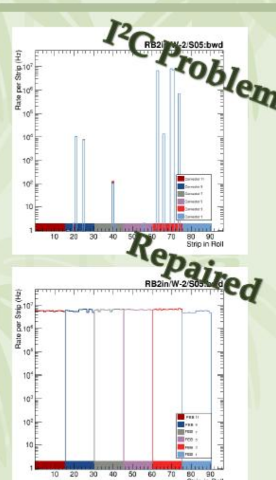
We thank our Atlas colleagues for their help in this matter!

A. Cimmino – RPC 2014, Beijing 13

Channel Connectivity & Functionality

- The control over the Front End Board thresholds is provided with use of the Inter-Intergated Circuit (I^2C) bus.
- I^2C communication problem can require partial or total chamber extraction.





A. Cimmino – RPC 2014, Beijing 16

Conclusions

- Long shutdowns are opportunities for detectors to perform commissioning and upgrade operations.
- During LS1, RPCs at CMS are performing HV, LV, and Gas system consolidation and upgrade interventions. All RPC software is being upgraded and improved, in line with CMS specifications.
- Before LS1
  - the number of inactive channels were ~2%.
  - The gas leak was 644l/h
- After the first commissioning interventions
  - ~51% of the gas leak has been reduced
  - 1.11% of all electronic channels have been recovered.
- Channel connectivity and functionalities are controlled after all intervention that require uncabling&recabling.
- The 4th Endcap station is being built. The positive side chambers are already installed and under test.

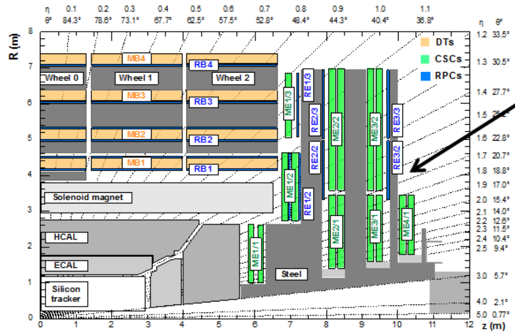
A. Cimmino – RPC 2014, Beijing 21

COLAFRANCESCHI, Stefano (CMS)

Resistive Plate Chambers for 2013-2014 upgrade of CMS

Motivation

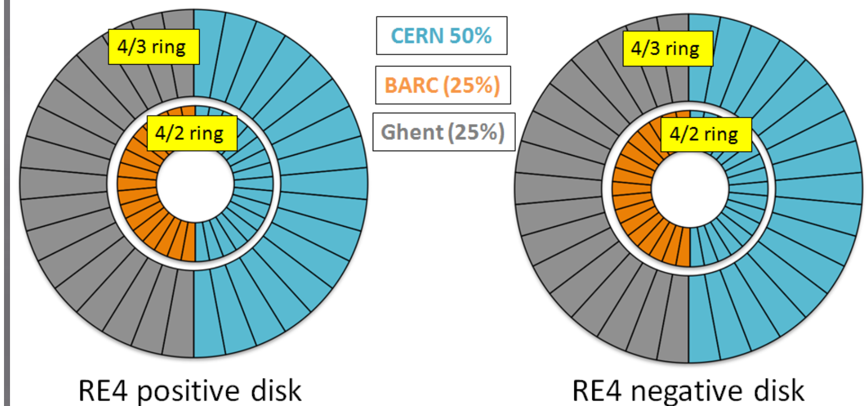
The CMS Muon System relies on three different gas detector technologies:
Drift Tubes (Barrel)
Cathode Strip Chambers (Endcap)
Resistive Plate Chambers (Barrel and Endcap)



During 2013-2014, the upgrade of RPC system provided the 4th station

The CMS endcap Muon system, before the upgrade was not redundant to sustain the trigger rate at the post LS1-increased luminosity while preserving high trigger efficiency.

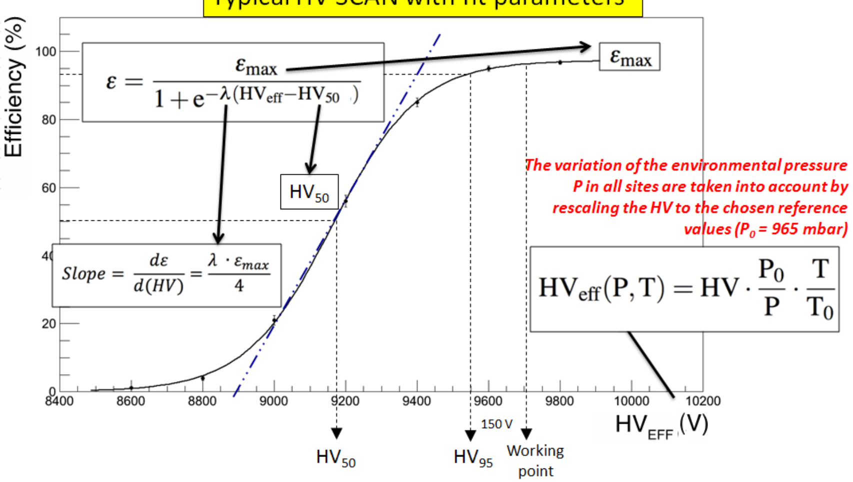
THE CMS ENDCAP DISKS



The detector assembly and qualification took place at three different assembly sites: Ghent University (Belgium), BARC Laboratories (India), CERN 904 (Switzerland)

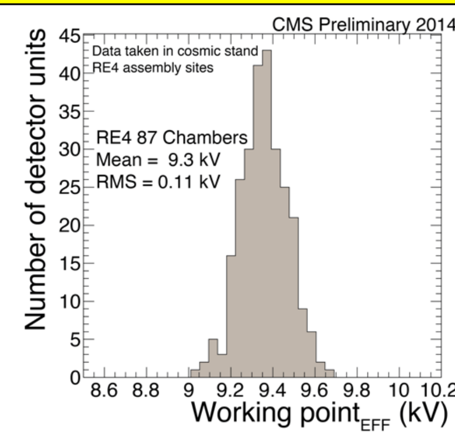
CHAMBER PERFORMANCE

Typical HV SCAN with fit parameters



CHAMBER PERFORMANCE

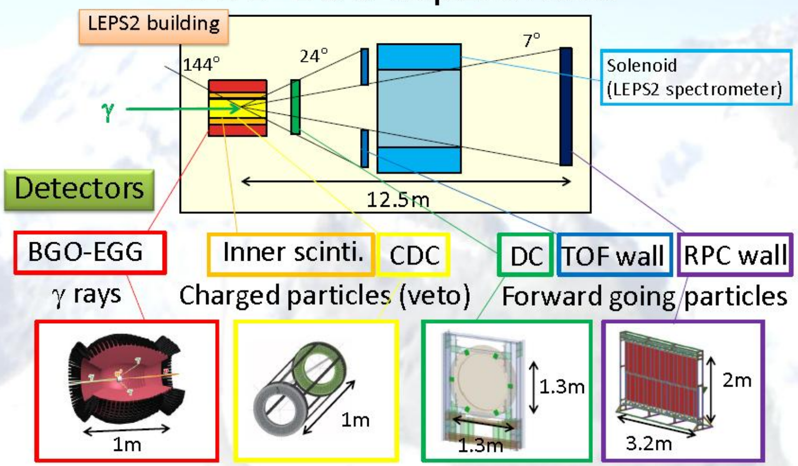
Distribution of the expected working point extrapolated by the individual HV scan chamber by chamber. Working point is defined as HV(95%) + 150V.



TOMIDA, Natsuki (Kyoto University)

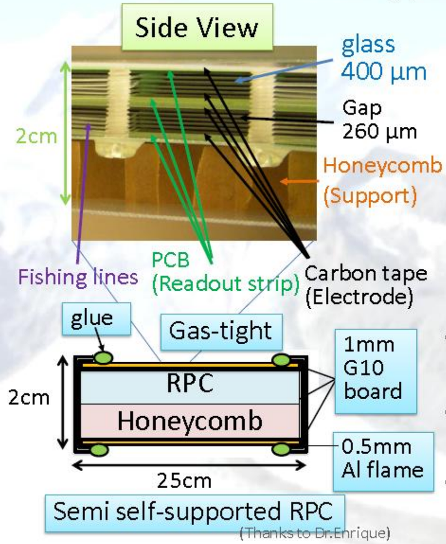
Forward TOF-RPCs for the BGO-EGG experiment at LEPS2

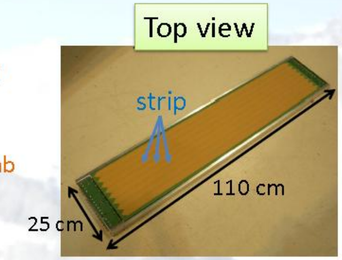
BGO-EGG experiment



- Missing resonances search (decay to multi π, η (multi γ))
- Mesic nuclei search (η′)

Prototype RPC

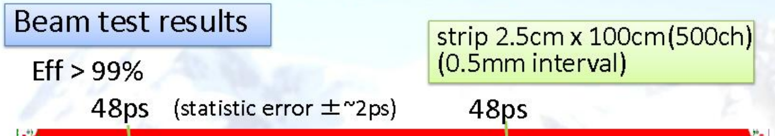




- 5 gaps x 2 stacks
- Electrode: carbon tape (10~100MΩ/sq)
- Readout strip : PCB print (Thanks to Prof. Wang)
- Gas volume ~ Active area (Small dead space)

Taiwan FEEs

Beam test results



50ps resolution ! with no big position dependence

(Meet with the BGO-EGG requirement)

- However, the Taiwan amplifier is unstable and sometimes starts oscillation
- Need treatments to make ground stronger

Summary

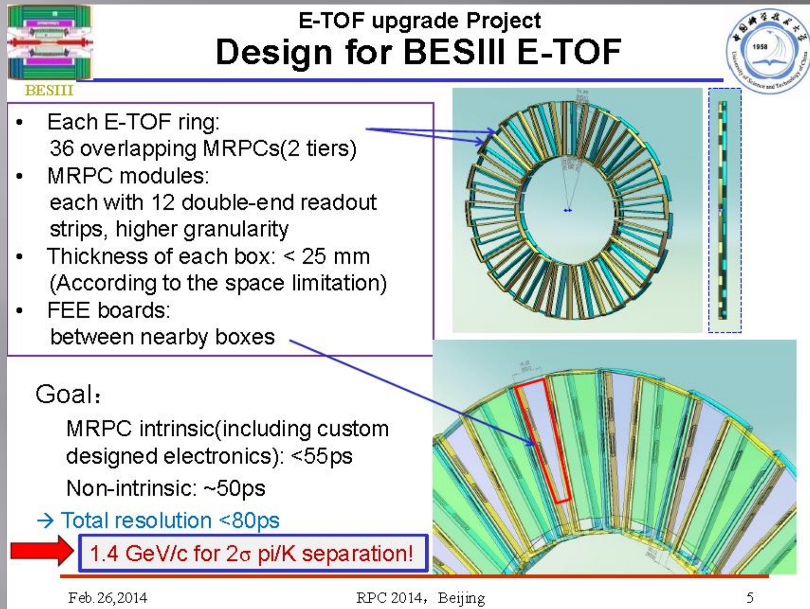
- Large strip, high time resolution RPCs are developed for the BGO-EGG experiment at LEPS2
- FEEs directly connected to readout strips are effective to reduce the reflection due to impedance mismatch
- A technique to reduce the number of readout electronics at FEE level worked effectively

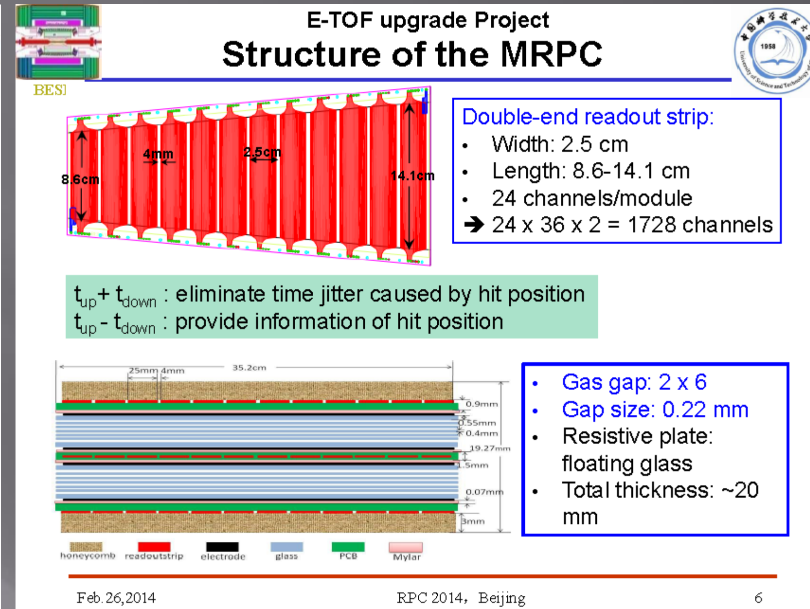
-> Achieved σ_{TOF}=50ps with 250 cm²/ch strips & FEEs

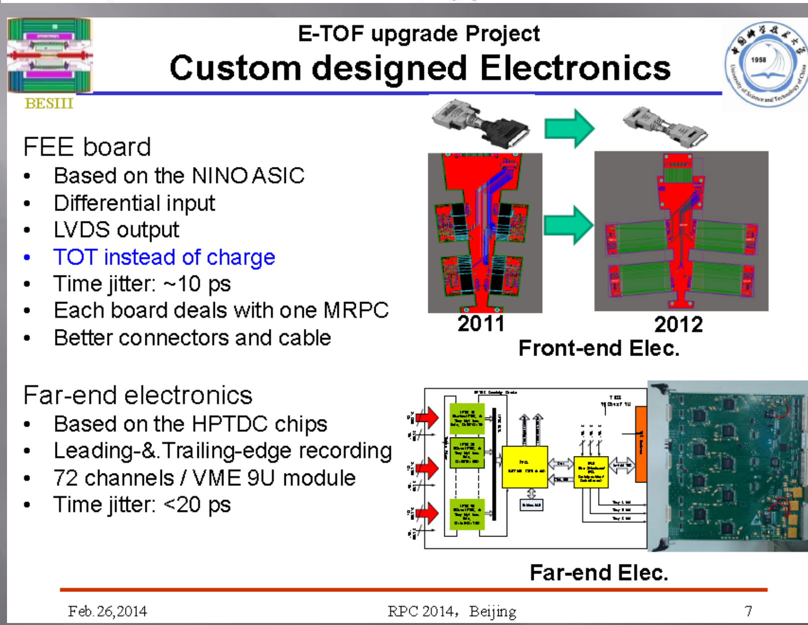
- We started production/installation of the BGO-EGG RPCs with Taiwan FEEs
- We will also develop the LEPS2 spectrometer RPCs on 2015 (FEEs have not been determined)
- I am glad if I can get advises about FEEs for large strips and about the treatment of the oscillation from experts

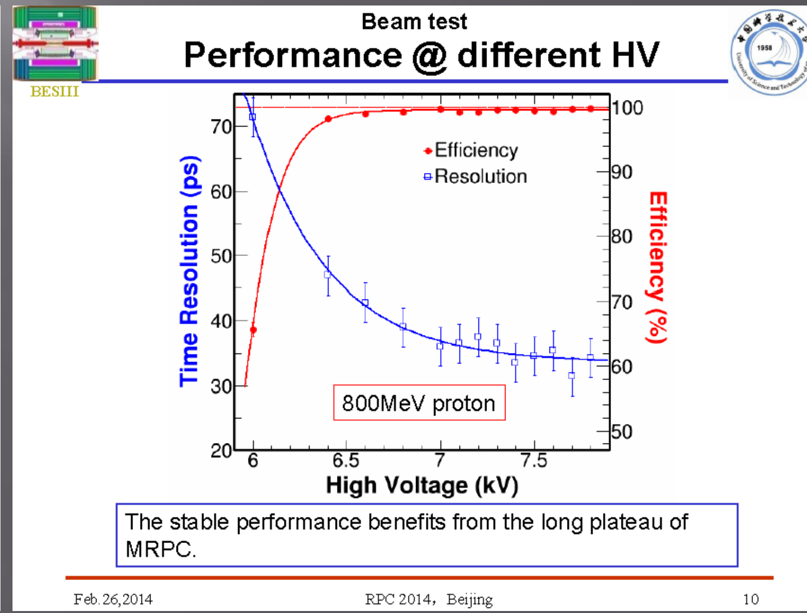
YANG, Rongxing (Univ. of Sci. & Tech. of China

The MRPC for the upgrade of the BESIII E-TOF









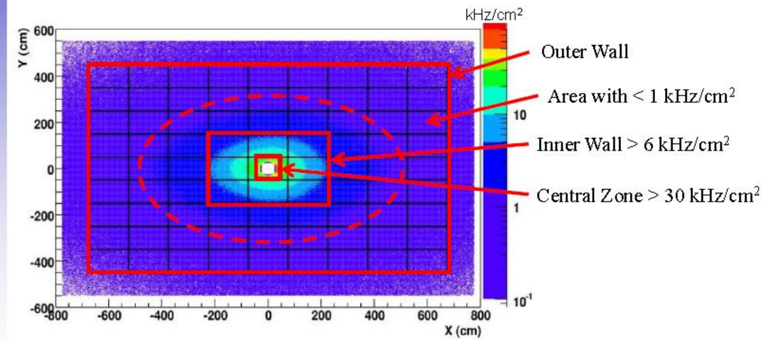
DEPPNER, Ingo (CBM-TOF Group)

The CBM time of flight wall – System aspects

Wall Arrangement and Flux

CBM ToF

URQMD simulated charged particle flux for mbias Au + Au events at 25 AGeV assuming an interaction rate of 10 MHz



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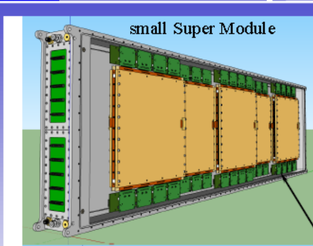
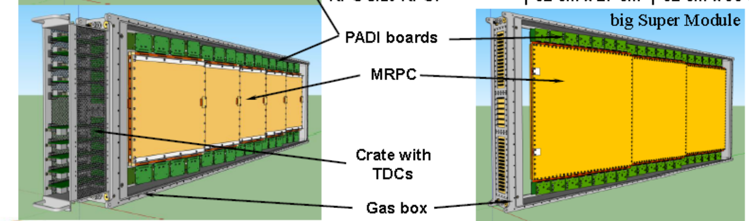
Conceptual Design of the Super Modules

CBM ToF



Module Properties	small SM	big SM
# RPCs per module:	5	3
# strips:	160	168
# channels:	320	336
PADI inside the box	yes	yes
total active area:	152 cm x 27 cm	152 cm x 53 cm
overlap	h: 2 cm v: 2 cm	h: 2 cm v: 3 cm
box size 180 cm x	49 cm x 11 cm	74 cm x 13 cm
tilting angle of the RPC:	8.7°	7.0°
RPC size RPC:	32 cm x 27 cm	52 cm x 53 cm



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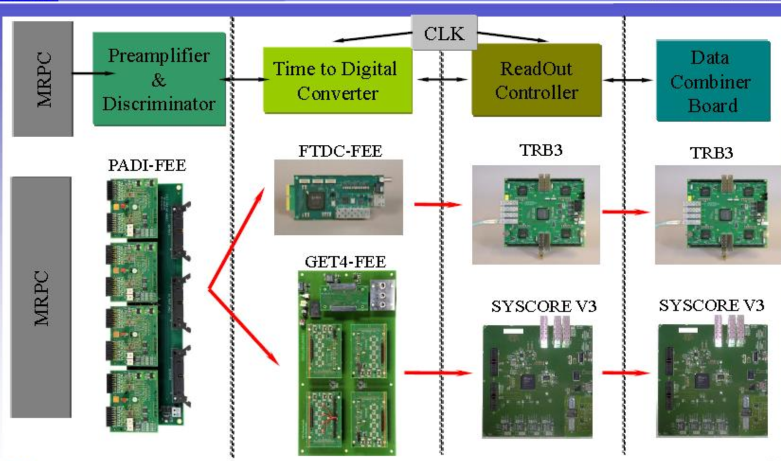
Electronic Readout Chain

CBM ToF



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Summary / Next steps

Summary

- A movable ToF-wall requires a very flexible design.
- The design of the differential MRPC for the outer wall is driven by the free-streaming readout ⇒ impedance matching is realized.
- For the inner wall two different concepts are available.
- All available types of RPC detectors fulfill the CBM ToF requirements in a spot response.
- Since the gas exchange in the gas gaps of the counters is dominated by diffusion, the performance of all RPC types has to be tested under full load conditions only available with heavy ion beams (@ GSI).

Next steps

- Building a complete super module for outer wall incl. electronics till fall this year.
- Load test for all available full size prototypes in April 2014 with heavy ions at GSI.
- Selection of the different layouts and counter configurations this year based on system aspects.

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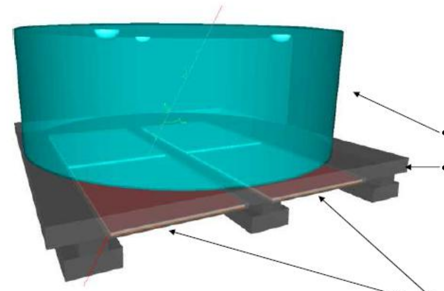
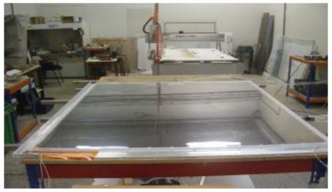
LOPES, Luis (LIP)

MARTA STATION

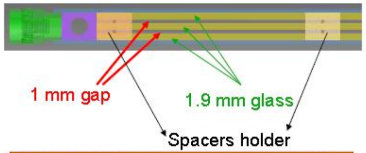
Muon Auger RPC Tank Array



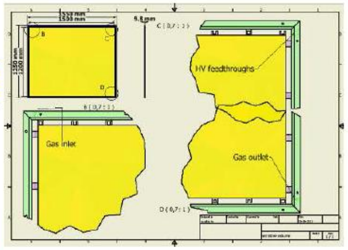
RPC MODULE



Glass RPC in avalanche mode

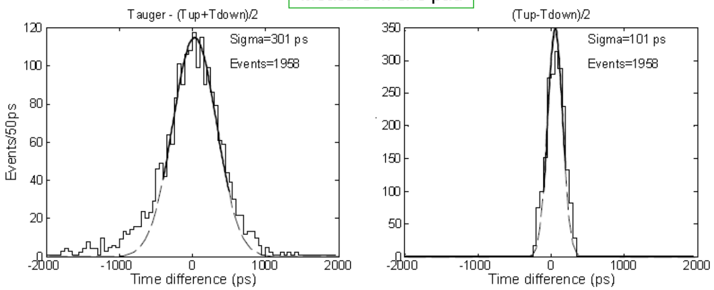


100 % R-134a, small commercial bottles



Analysis – Time Resolution

RPC-telescope | Measure in one pad | Telescope



$$\sigma_{auger} = \sqrt{301^2 - 101^2} = 283\text{ps}$$

Some dependencies (longitudinal position p, ex) remain uncorrected

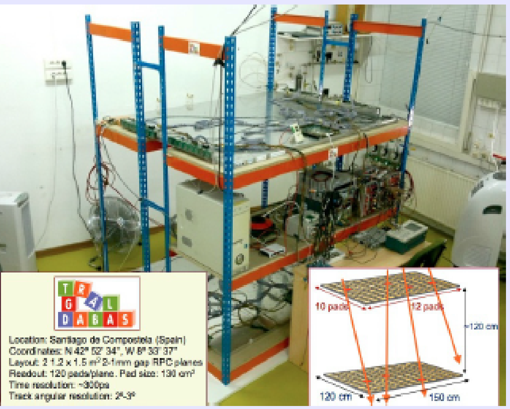
CONCLUSIONS

- After 3 months operating at 1 cc/min none undesirable effects were observed in the chamber performance, when compared with larger gas flow rates
- Charge, streamer fraction and efficiency "only" depends on E/N (reduced electric field).
- Time resolution below 300 ps σ.
- Efficiency levels uniform over all detector area.
- More than 10 RPC units already construct and in operation in 4 (2 continents) different places. Proving the robustness and easy operation…
- Once the practical quantities are well correlated with E/N, we can control them monitoring environment and adjusting the High Voltage, keep the efficiency at stable values over time.

KORNAKOV, Georgy ((Darmstadt Tech. Univ)

A new RPC based detector for the regular study of cosmic rays

TRAGALDABAS

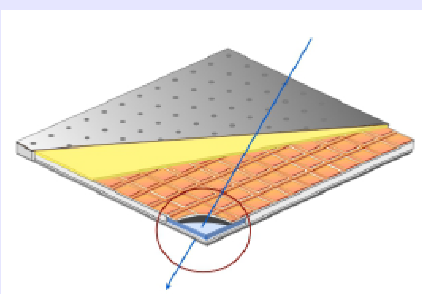


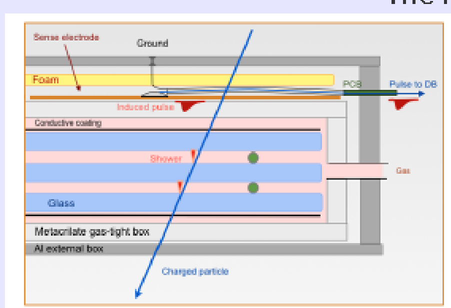
Tragaldabas (TRAsGo for the AnaLysis of the nuclear matter Decay, the Atmosphere, the earth B-Field And the Solar activity) is a cosmic ray detector, based on the RPC technology offering both high granularity and high time resolution together with tracking capability. It is based on the Trasgo initiative [D. Belver et al. NIMA 661 (2012) S163] that was proposed as an affordable alternative in comparison with other existing techniques.

The Tragaldabas is taking test data with 2 RPC planes, since Sept. 2013 in the Univ. of Santiago de Compostela) at a rate of about 7 millions of registered events per day. The present main performances (2 plates, at ~1.2m), are:

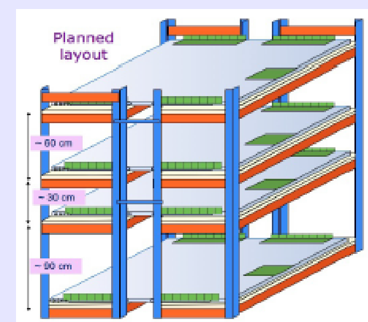
- **Granularity:** 120 pads / plane; pad size: 130 cm2
- **Acceptance:** ~ 5 srad
- **Angular resolution:** 2º- 3º
- **Time resolution:** ~300ps

The RPC cells





RPC layout	Width(mm)	X_0(cm)	ΔX_0
Al	3	8,9	0,034
Foam(dens=0.3)	8,7	142,0	0,006
Cu	0,03	1,4	0,002
PCB (FR4)	1,57	31,8	0,005
Metacrilate	1	40,8	0,002
Glass	1,9	3,2	0,059
R134a	1	26,5	0,004
Glass	1,9	3,2	0,059
R134a	1	26,5	0,004
Glass	1,9	3,2	0,059
Metacrilate	1,0	40,8	0,002
Al	3	8,9	0,034
Total	26		~0,27



The detector is composed by two RPC active planes of 1.2x1.5 m² size. Each plane is made by 3 slides of 2mm-glass with a 1mm gaps in between, placed inside a gas tight metacrilate box. A small flux of freon R134a is kept flowing to compensate the gas losses. The external side of the external glass plates is covered by a conductive coating where a +/- 5600V high voltage is applied. The read-out is done by Cu pads placed out of the metacrilate box, separated by straight guard-electrodes 6mm wide to prevent the crosstalk, that is almost negligible.

IUPPA, Roberto (INFN, Tor-Vergata)

POTENTIAL OF RPCs IN COSMIC RAY EXPERIMENTS FOR THE NEXT DECADE

GREX/**COVER**-PLASTEX EXPERIMENT

An EAS array, at Fly's Eye, University of Utah (early 1990s). The COVER extension (20 m² of RPCs) was deployed to measure the time-structure of the EAS.

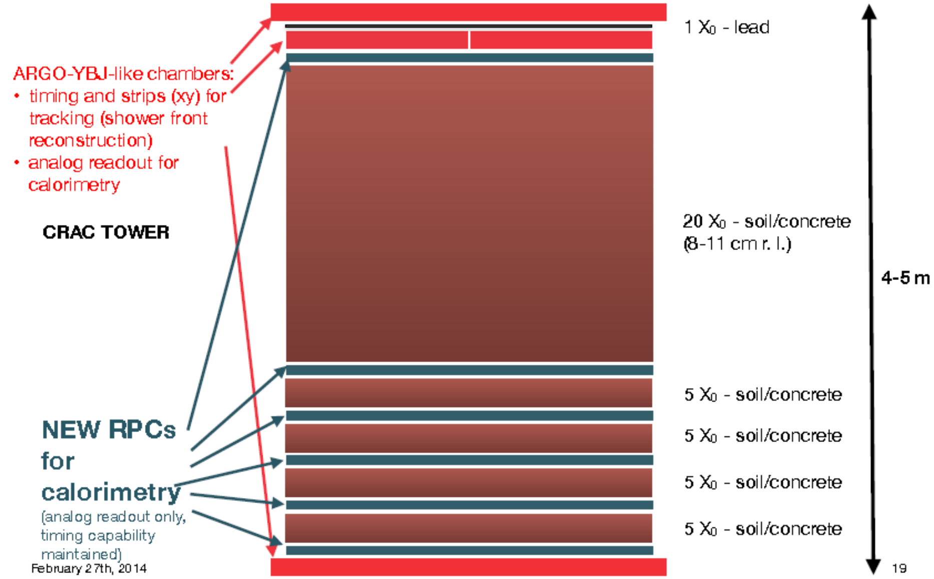
ARGO-YBJ EXPERIMENT

See Iacovacci's presentation, Mastroianni's poster and my previous presentation.
See also ahead.
One-technology experiment. Ultimate proof of robustness of RPCs.

R&D **AUGER**-oriented

Study of standalone RPC detectors for cosmic ray experiments in outdoor environment (L. Lopes, P. Fonte and M. Pimenta, RPC 2012)
See also the upgrade in the presentation of Lopes.
Really important: it would disclose the field of sampling was array to RPCs!

Cosmic RAy Calorimeter: CRAC



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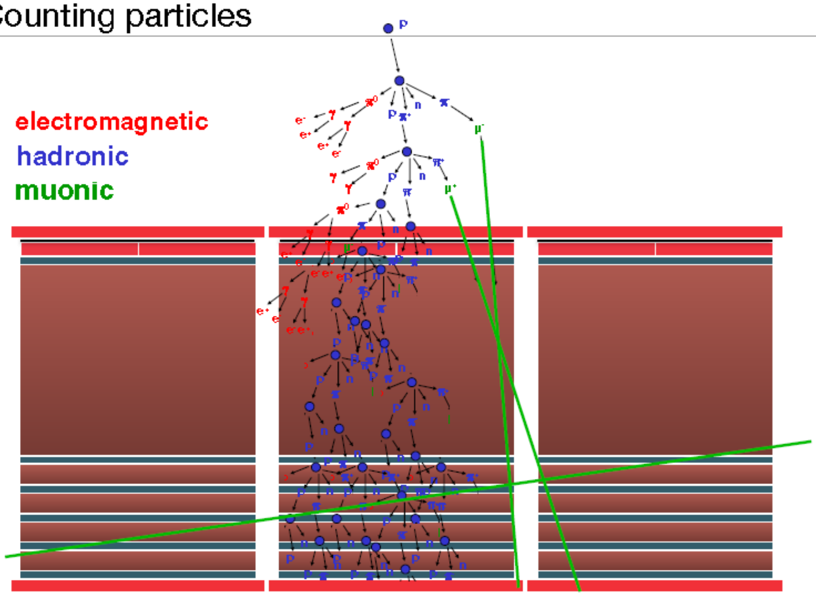
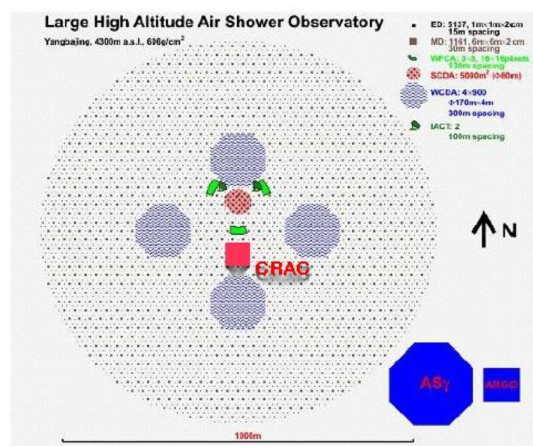
Counting particles



The Lhaaso project

CRAC is thought to work at high altitude and a natural framework for it is the LHAASO observatory, a Chinese-driven 1 km² project to be built in the Yunnan province (4400 m. a.s.l.).



With LHAASO detectors around it, CRAC would benefit of extra experimental information to be used for calibration, multi-channel air shower physics and so on.

NAIMUDDIN, Md (Delhi University)

Study of various properties of glass and bakelite electrodes for RPC

Choice of Electrodes

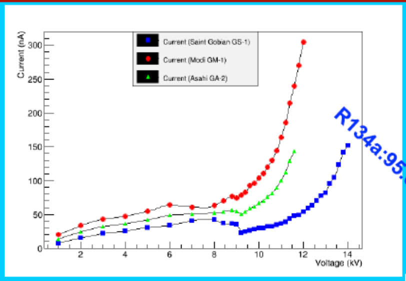
- The parameter that must keep in mind for material selection:
  1. **High Resistivity** : Controlling Time Resolution ,Counting rate, prevent Spreading of Discharge
  2. **Smoothness of Surface**: Avoid localisation of Excess Charge, Prevent Alternating leakage path for post Streamer recovery.
- Material Used:
  - **GLASS** : Saint Gobain, Asahi and Modi

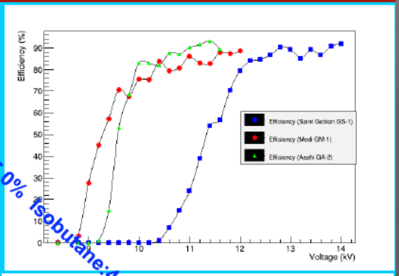
  For First Parameter we determined:
  - **Bulk Resistivity**
  - **Surface Resistivity**
- For Second Parameter we performed :
  - **XRD**
  - **SEM**
  - **AFM**

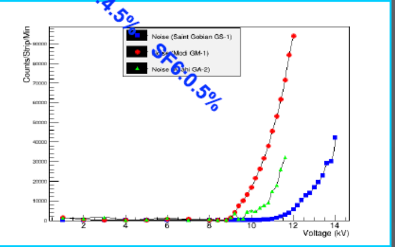
EDX Study

Glass Name	Asahi	Saint Gobain	Modi
Formula according to percentage of Element	$C_5Na_7Mg_2Al_{0.3}Si_{22}Ca_3O_{62}$	$Na_8Mg_2Al_{0.3}Si_{25}Ca_3O_{62}Sn_{0.6}F_1$	$C_7Na_6Mg_2Al_{0.3}Si_{20}Ca_2O_{62}K_{0.2}$
C	4.89		6.68
Na	6.89	8.22	6.34
Mg	1.79	1.85	1.55
Al	0.32	0.27	0.31
Si	21.73	24.56	20.44
Ca	2.71	3.32	2.45
O	61.67	59.97	61.99
Sn		0.58	
F		1.22	
K			0.24
S			
Cl			
Fe			
Total	**100**	**99.99**	**100**

Properties – Standrad Mixture







- All three samples shows about 90% efficiency
- Modi has the maximum noise and Asahi has minimum.

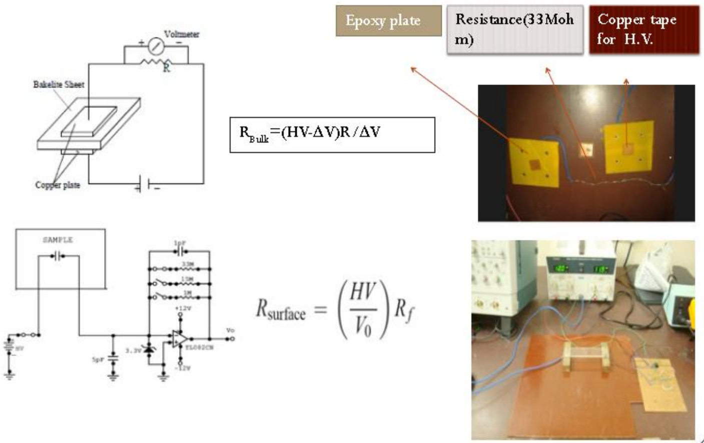
Conclusions

- **Studies of three local glass electrodes and RPC's made up from them were performed.**
- **An efficiency of more than 90% observed for all the three electrodes under all conditions.**
- **Controlling the humidity inside the cavern is very important to control the current.**
- **Asahi appears to be best suited for INO RPC. With small amount of SF6 Saint Gobain also look good.**
- **More studies like ageing effect, time resolution, etc. are ongoing.**

KUMAR, Ashok (Delhi University)

Study of RPC Electrodes and Detector Performance with varying gas composition, temperature and humidity

Bulk and Surface Resistivity measurement circuit for Bakelite



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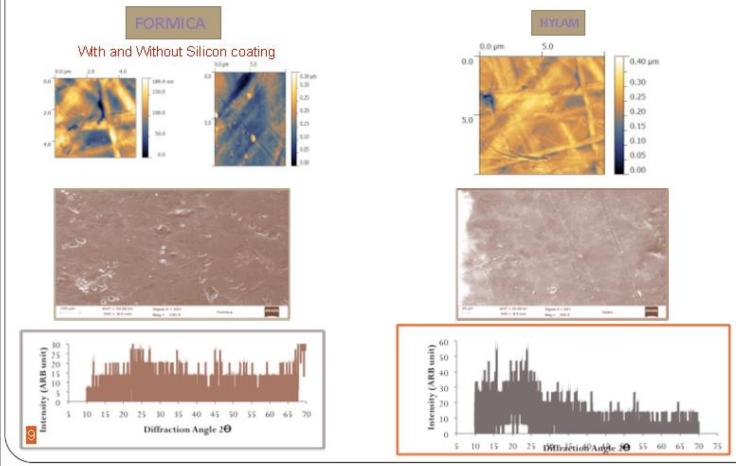
Monday, February 24, 14

AFM ,SEM, XRD of Bakelite



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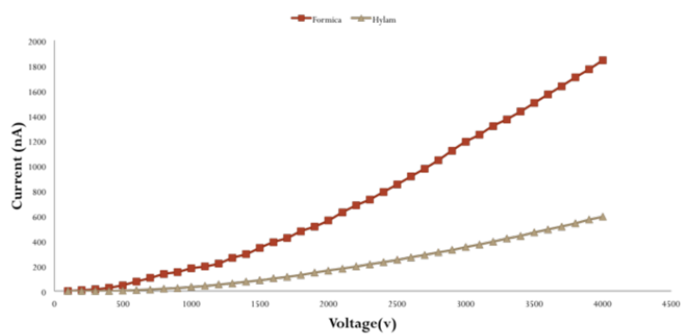
Monday, February 24, 14

V-I Curve for Bakelite



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Monday, February 24, 14

Summary

- ➔The R&D effort for the bakelite RPC is presented keeping in view their use in upcoming India based Neutrino observatory (INO).
- ➔ We need ~ 30k RPCs so the need is essentially to have low cost and readily available solutions.
- ➔Since Hylum and Formica are available locally, their studies have been performed so far.
- ➔Next step is to get better variety of electrodes and perform studies.

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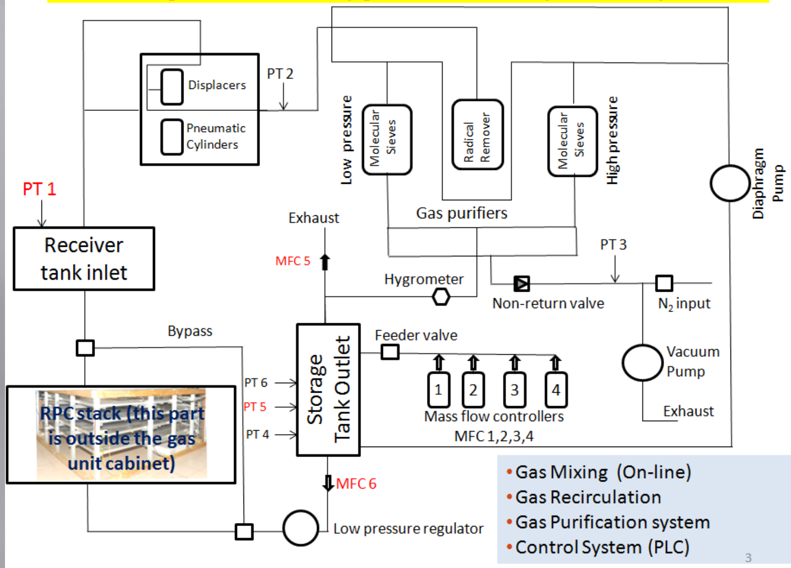
Monday, February 24, 14

KALMANI, Suresh (TIFR)

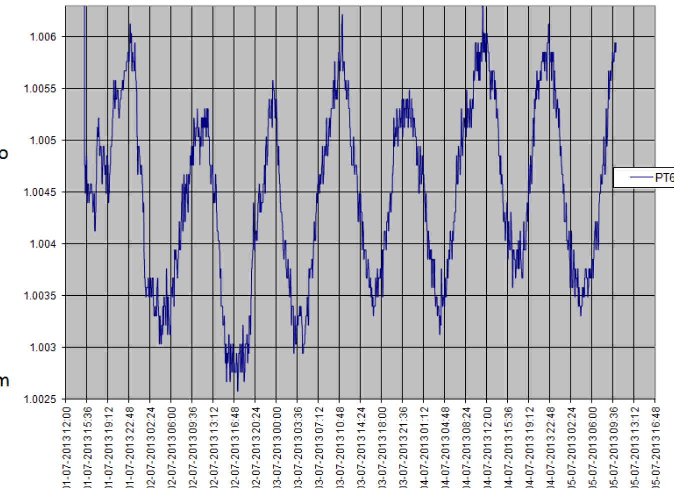
Effect of ambient pressure variation on the closed loop gas system for the INO RPCs

Line diagram of the close loop gas recirculation and purification system



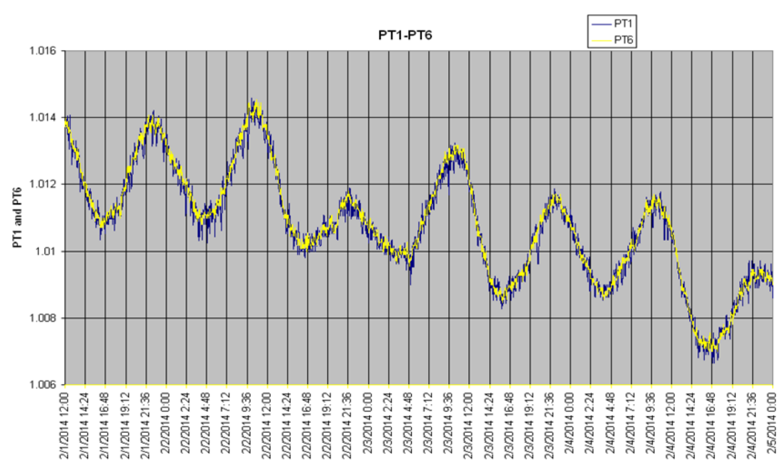
Variation of Lab air pressure

Lab pressure (PT6) varies over a day. Average variation is 2 to 3 millibar. Maximum pressure appears at 10am and 10pm. Minimum pressure appears at 4am and 4 pm.



Introducing an external sensor :PT1 follows PT6

- PT1 is system pressure
- PT6 is Lab pressure also taken as SP2 DIFF



Conclusions

- Closed loop gas system for 12 RPCs was built
- Long term study of the same was carried out
- Ambient pressure problem encountered and solution was implemented
- Fine tuning of the system needed:
  - Wait and test for one more monsoon
  - Detailed gas analysis
- System design for engineering module is in progress

Plan of the talk

- Introduction
- Detector R&D
- Signal Readout
- Detector performance
- New deployments
- Applications
- Outlook

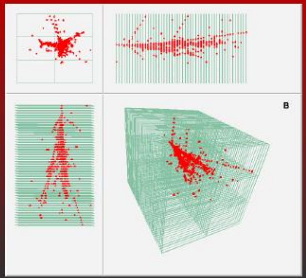
REPOND, Jose (ANL)

RPCs for Imaging Calorimetry: the DHCAL project

The DHCAL

Description

54 active layers
Resistive Plate Chambers with 1 x 1 cm^2 pads
→ ~500,000 readout channels
Main stack and tail catcher (TCMT)



Electronic readout

1 – bit (digital)
Digitization embedded into calorimeter

Tests at FNAL
with Iron absorber in 2010 - 2011

Tests at CERN
with Tungsten absorber 2012

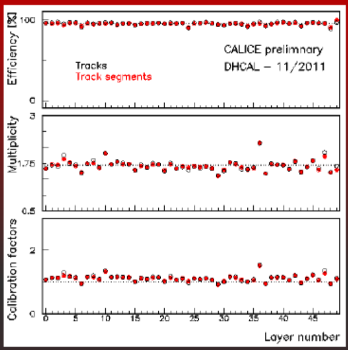
Measurements with muons

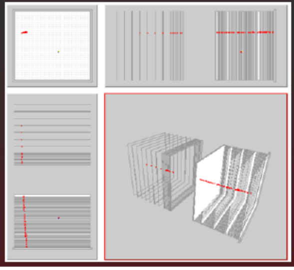
Muons

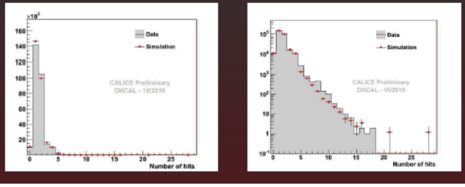
Produced with 32 GeV/c beam and 3m Fe-block
Used to measure the performance of individual RPCs

Efficiency ε
Average pad multiplicity μ
→ Calibration factors c = εμ

Used to tune the MC simulation of the RPC response



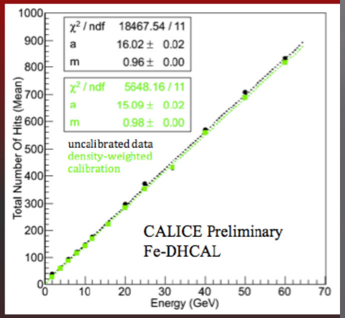


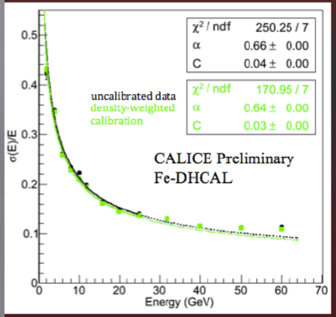


Measurements with Pions and Fe-absorber

Response

(Density-weighted) calibration improves results
Close to linear up to 60 GeV
Fit to power law aE^m, where m is measure of saturation





Resolution

Calibration improves resolution somewhat
Saturation (=multiple hits/pad) degrades resolution > 30 GeV
Stochastic term of 64%/√E (adequate for hadron calorimetry)

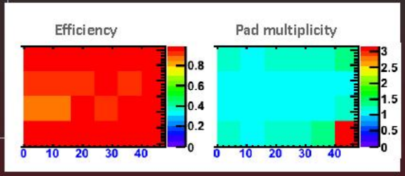
Further R&D: 1-glass RPCs

Offers many advantages

Pad multiplicity close to one
→ easier to calibrate
Better position resolution
→ if smaller pads are desired
Thinner
→ saves on cost
Higher rate capability
→ roughly a factor of 2

Status

Built several large chambers
Tests with cosmic rays very successful
→ chambers ran for months without problems
Both efficiency and pad multiplicity look good



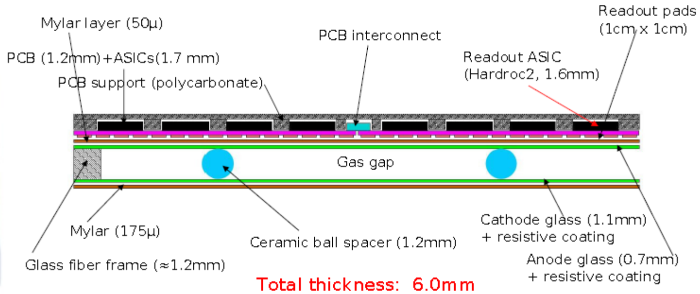
GRENIER, Gerald (IPN Lyon)

A hadronic calorimeter with Glass RPC as sensitive medium

Chamber cross-section view

•1 m2 GRPC

- Saturated avalanche mode : spatial charge distribution on glass anode ~ 1 mm^2
- Read by pad 1 cm^2 copper pads : max particle density in shower ~ 100/cm^2 : 3 readout thresholds.
- Embedded readout electronics



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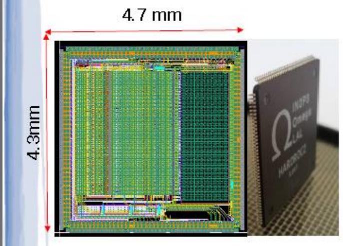
Readout electronic



- ASICs=HARDROC2 (http://omega.in2p3.fr)
- Each ASIC reads 64 copper pads,
  - Amplification, shaping
  - 3-level discriminator (dynamique range 10 fC to 30 pC)
  - triggerless : store up to 127 first threshold crossing (pad ID and time (200 ns clock))
- ASICs are daisy-chained
  - data readout
  - configuration
    - thresholds values
    - amplification gain per pad (response uniformity)
    - etc ...

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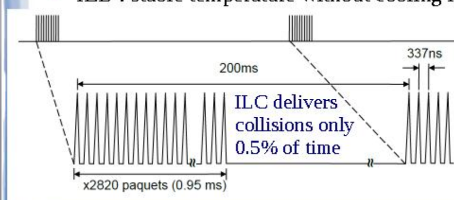
Power pulsing

- ILD : stable temperature without cooling inside detector ⇒ < 10 µW/channel



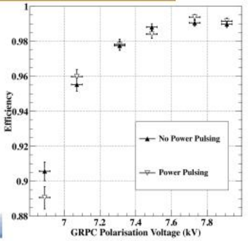
HARDROC2 use

1.5 mW per pad *0.5%=7.5µW/channel

TTL controllable ASIC switch off (I<4µA) and on (I~28 mA).

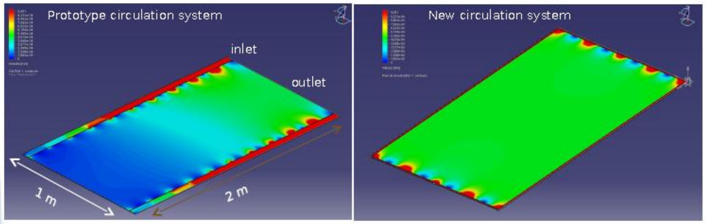
Power-Pulsing mode was tested in a **magnetic** field of **3 Tesla**

The Power-Pulsing mode was applied on a GRPC in a 3 Tesla field at H2-CERN (**2 ms every 10 ms**)
No effect on the detector performance

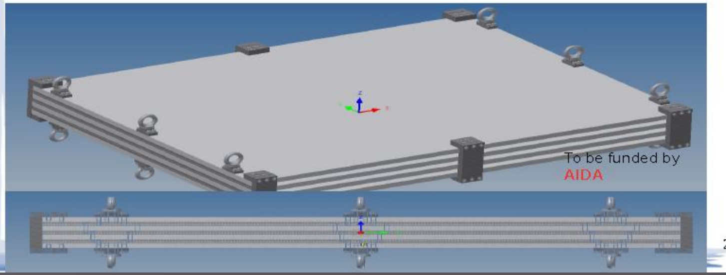


RPC 2014

Detector improvement : to achieve same performances with very large GRPCs

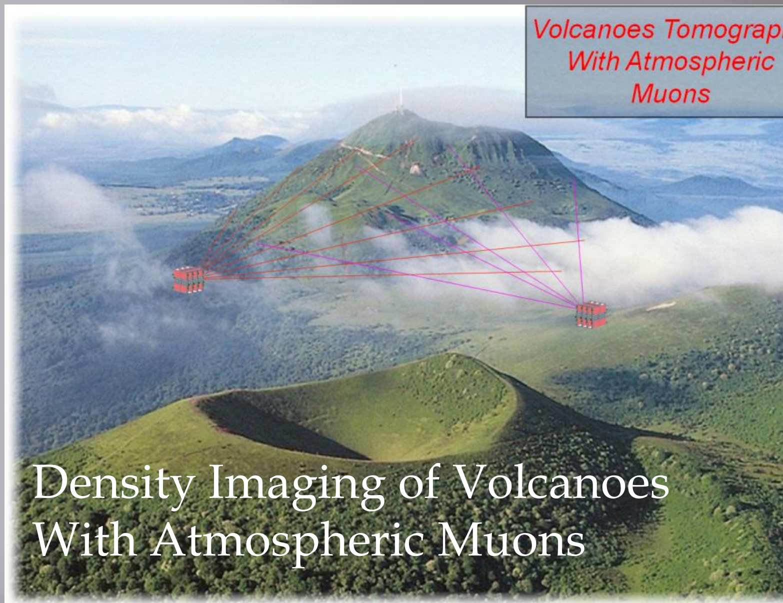


Mechanical structure : to be built with EBW techniques and to host few large detectors GRPCs

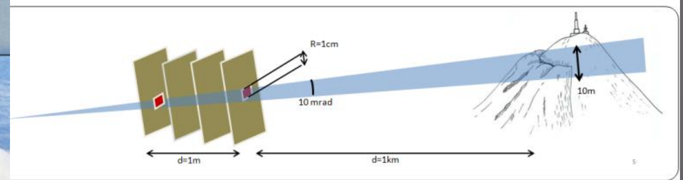


23

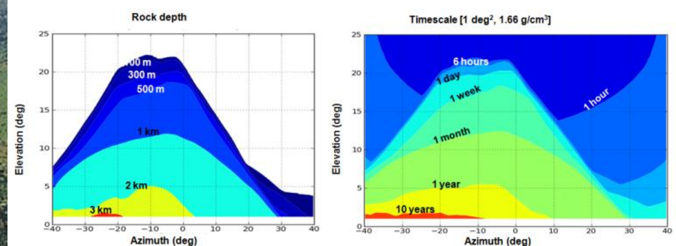
IMAD, Laktineh (CNRS/IN2P3)



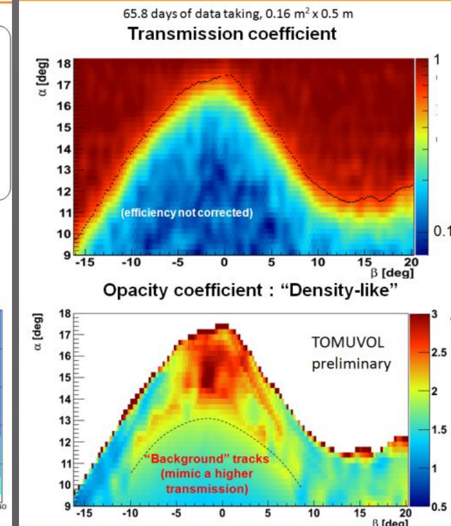
The muography in a nutshell ...



Muons crossing the volcano is a powerful tool to explore its structure density. A resolution of 10-20 m is needed to achieve a relevant study from the geological point of view.

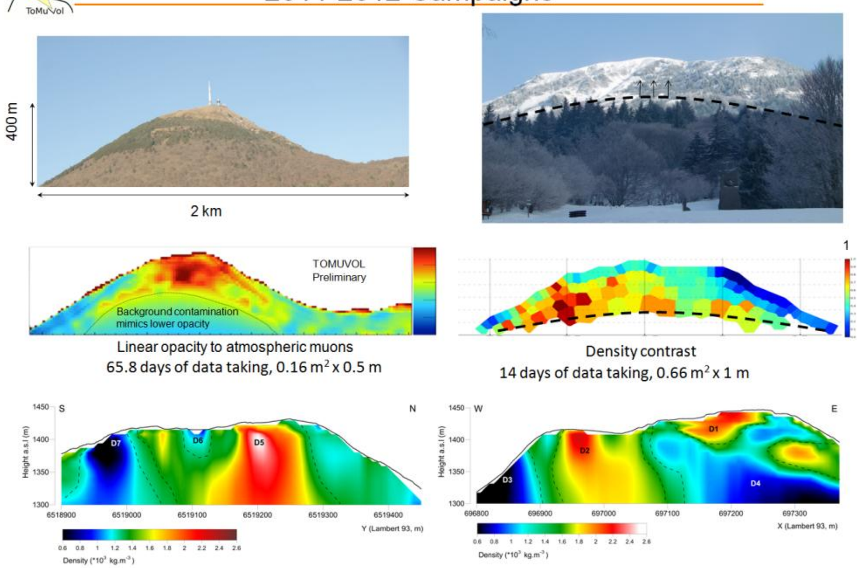


Computation for a uniform target with ρ=1.66g/cm³ and 1 m² ideal detector



al contrast in the summit area. At the base, background mimics

2011-2012 Campaigns



Conclusion

RPC detectors equipped with electronics readout are very powerful tool providing structural information from remote location (km). 10 mrad resolution seems achievable, with few percent contrast.

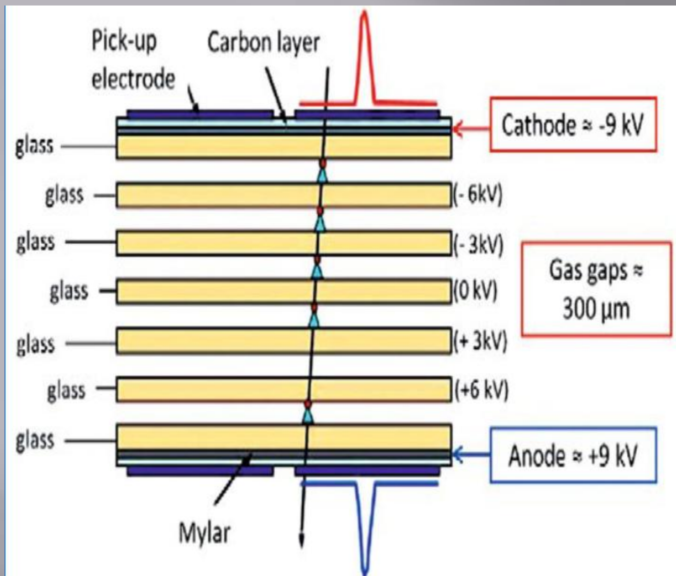
Spare SDHCAL detectors allowed to define a good muon telescope.

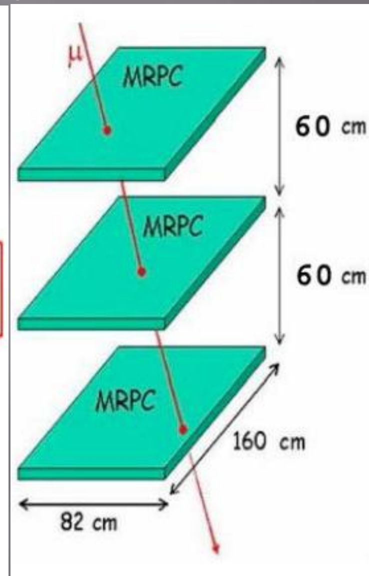
The data acquired in 2011 / beginning 2012 fully demonstrate the potential of the method.

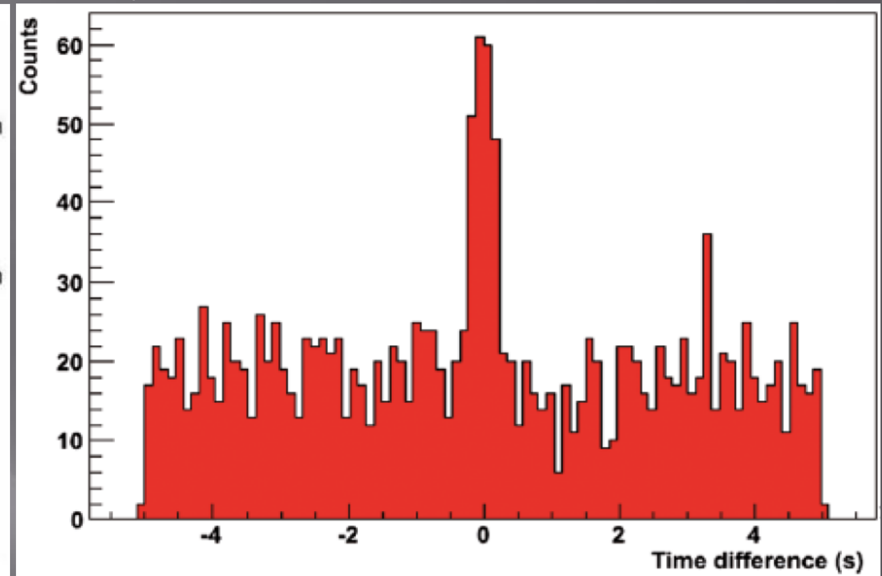
The TOMUVOL detector was completed in 2013. Excellent quality tracks were collected in a short period of time. New data taking campaign will start soon and new techniques to probe the volcanoes structure will be developed.

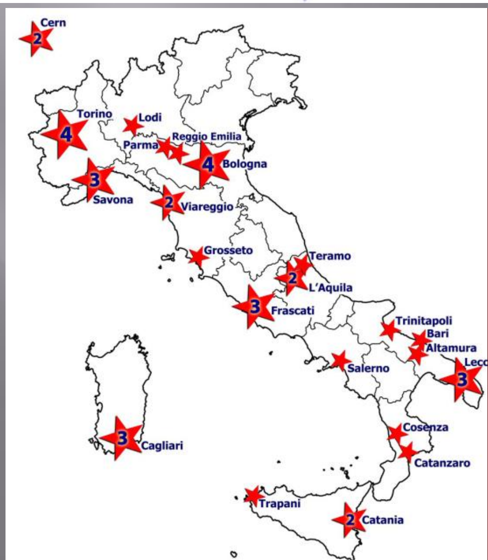
DE GRUTTOLA, Daniele (INFN)

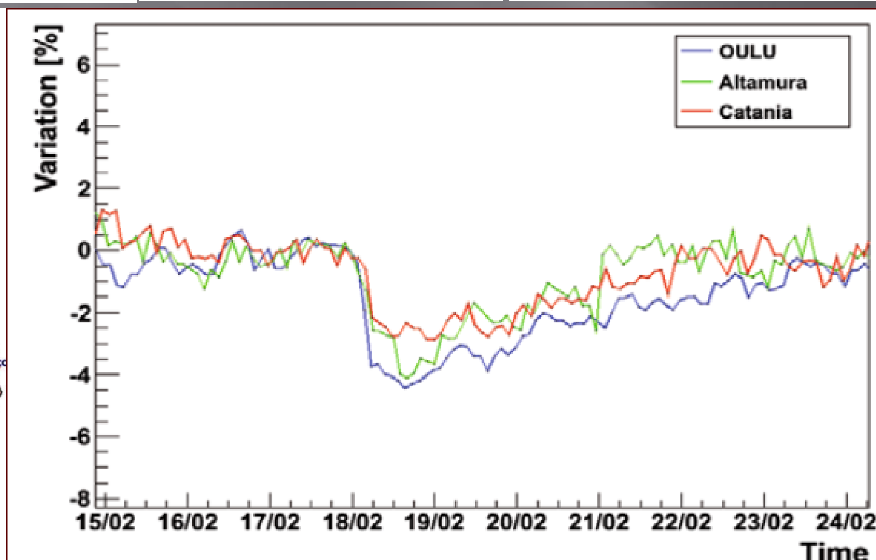
A MRPC telescope array for the EEE Project









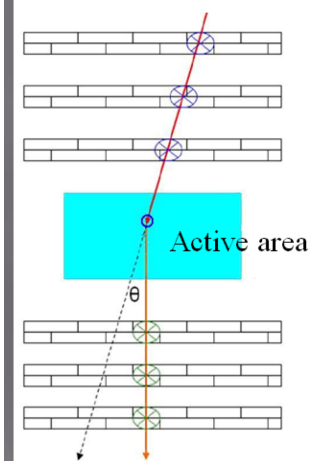


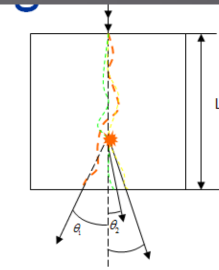
The Forbush decrease following the large X2 solar flare on mid-February 2011 has been observed by the muon telescopes of the EEE Project, which are located in several italian sites and at CERN. Data from two different telescopes of the EEE network have been analyzed and compared to those measured by neutron monitor stations

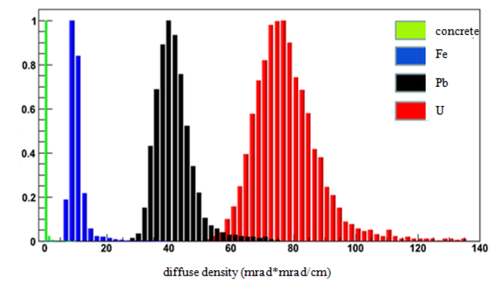
SHI, Li (Tsinghua University)

A high time and spatial resolution MRPC designed for muon tomography

- Muon tomography is a potential technology growing up in recent years which can use cosmic ray as particle resource. And another advantage of this imaging is that the detected objects will nearly not get influenced.
- The key technique to this application is to develop detectors with sub-millimeter position resolution and large active area. Some other methods have been tried to achieve it, such as GEM and drift chamber.

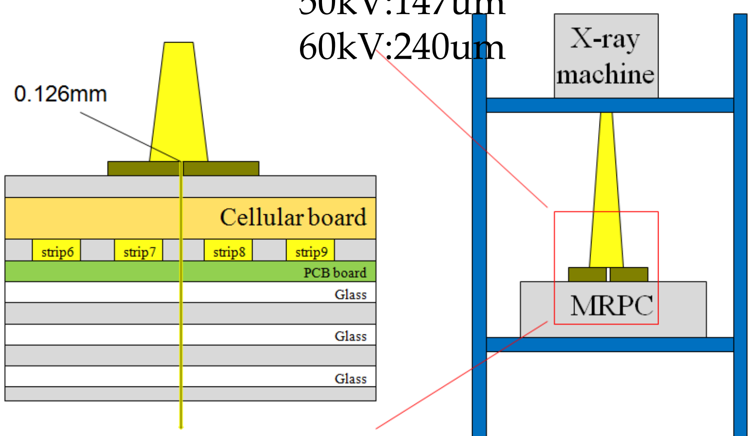


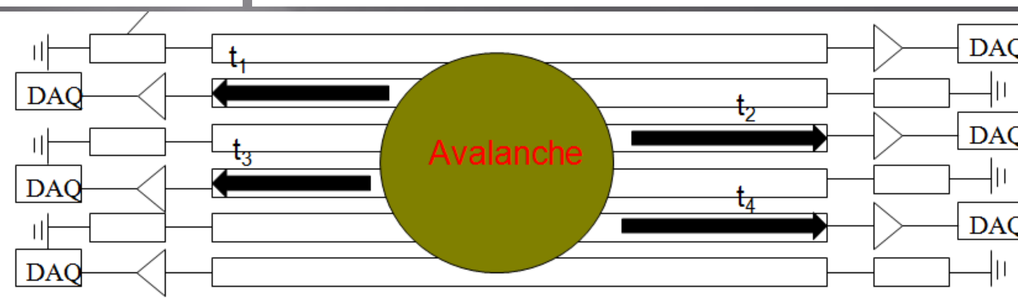


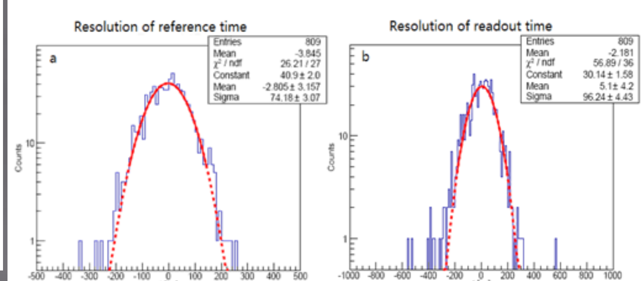


X-ray test

Position resolution:
40kV:120um
50kV:147um
60kV:240um







$$t_{ref} = \frac{t_{PMT1} + t_{PMT2} + t_{PMT3} + t_{PMT4}}{4}$$

$$t_{MRPC} = \frac{t_1 + t_2 + t_3 + t_4}{4}$$

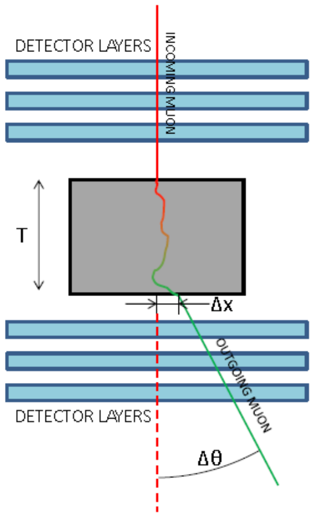
$$\sigma_{MRPC} = \sqrt{\sigma_{t-MRPC}^2 - \sigma_{t-ref}^2} = 65 \pm 5ps$$

Towards a RPC-based muon tomography system for cargo containers

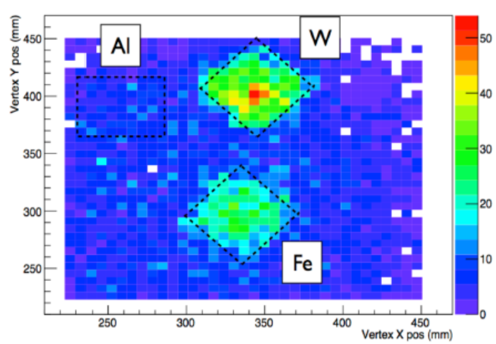
- Muons undergo multiple coulomb scattering within the detector volume.
- The angular distribution can be assumed to be Gaussian, with σ^2_0 depending on the radiation length X_0 (and ultimately on ρZ^2).
- Muon tracks scattering within the target volume provide information of its content.
- High sensitivity to high-Z, high-density materials.

$$\sigma_0^2 \approx \left(\frac{15MeV}{pc\beta}\right)^2 \frac{T}{X_0}$$

$$X_0 \approx \frac{A \cdot 716.4}{\rho \cdot Z \cdot (Z+1)\ln(287/\sqrt{Z})}[cm]$$



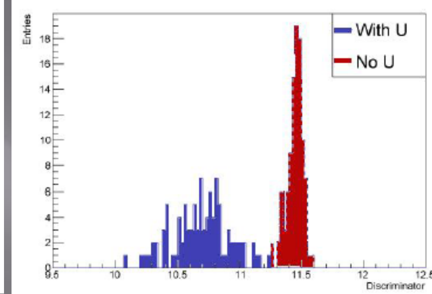
- Simple proof of principle:
  - Plot vertices with scatter angle above 0.03 rad
  - No momentum information
- Plot from prototype data:
  - Metal cubes 5 cm x 5 cm x 5 cm
  - Aluminium, iron, tungsten
- Clear separation between high and low Z materials.

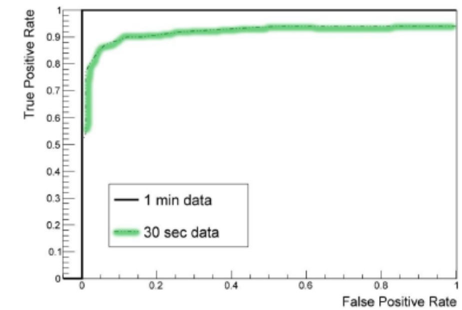


28/02/2014

Clustering algorithms

- Discriminator value is used as binary classifier, based on a pre-defined threshold.
- Evaluate classifier by comparing true positive and false positive rate on 100 sets of 1 minute simulated cosmics.
- Assuming perfect momentum information, 1 minute of data is enough to reliably identify the block of U in most scenarios.



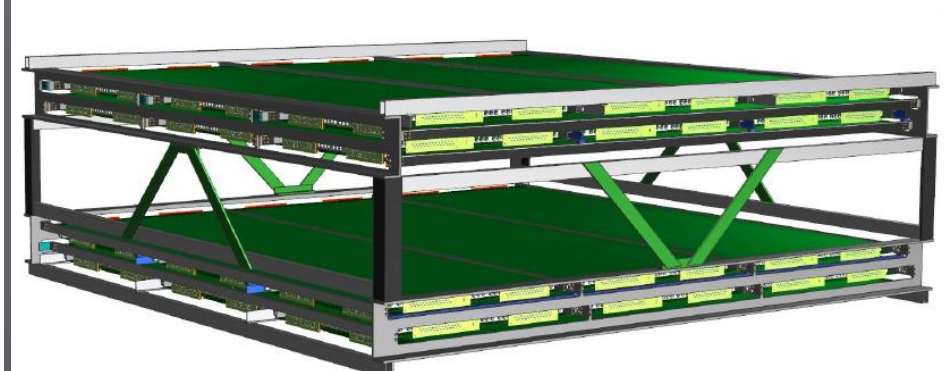


28/02/2014 Cargo container with stone 20

AWE is building a large size test setup in their facilities.

Large unit (1800 mm x 1800 mm) consisting of 6 RPC, in two orthogonal directions.

Modular construction to be used as a “detection tile”.



CHEN, Sidong (Peking University)

Simulation of a Small Muon Tomography Station System based on RPCs

2. Simulation

2.1 Simulation of the muon tomography station system

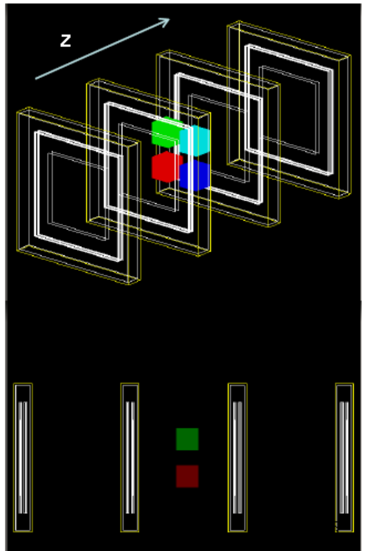
- Construct the station in Geant4：

- Sensitive range：20×20 cm^2
- 4 detectors placed along z-axis
- Spacing between detectors is 29 cm

- 4 objects of different material is placed in the detection zone:

6×6×6 cm^3 cube

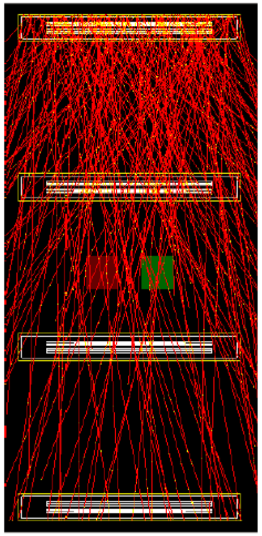
Light blue: aluminum
Dark blue: iron
Green : lead
Red : tungsten



2.2 Simulation of the cosmic ray muon

- We generate 2,000,000 (~21h) cosmic ray muons on the surface of the top detector in the range of 40 ×40 cm^2.
- Approximately 17,000 events are detected pass through all four detectors
- The acceptance angle is very limited because of the small sensitive range
- The counting rate is ~13.6/min

This number is consistent with our experiment



3. Reconstruction

- Using the Monte Carlo simulations, we test the performance of the station in tomographic reconstruction.
- Two algorithms are used: PoCA and EM
- PoCA (Point of Closest Approach): a simple algorithm can reconstruct image very fast. It assumes that the scattering occurred due to one single scattering event located in the PoCA point.
- EM (Expectation Maximization): use iteration to improve the quality of reconstructed image. It will cost a long time.

Conclusion

- Simulation work
- Our muon tomography station can be use to do reconstruction and material discrimination.
- It can do reconstruction using PoCA algorithm and performs better when EM algorithm is used.
- To have 90% chance to discriminate lead from iron with zero false positives requires ~40 min with precise momentum information and ~135 min with no momentum information.
- We can improve the performance of our station by just extend the sensitive range.
- When the sensitive range is extended to 1×1 m^2, the station's useful events counting rate increases approximate 26 times.
- The large RPC station can discriminate lead from iron by 90% chance in ~1 min with precise momentum information and ~5 min with no momentum information

YU, Baihui (Tsinghua University)

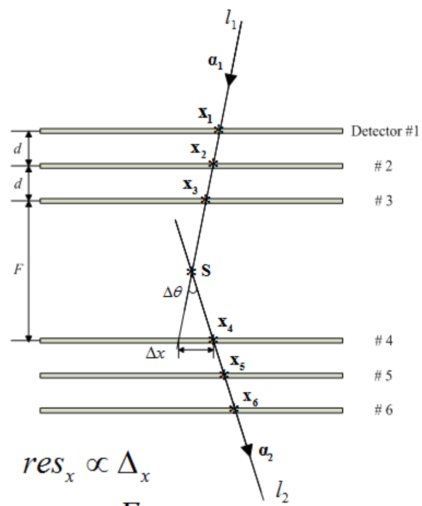
The Preliminary Analysis of the Influence of MRPC Detector Spatial Resolution to the Imaging Quality in Cosmic Ray Muon Tomography

A first impression…

Increasing detector separation d will make the track fitting more accurate, so Δ_θ (the error of the scattering angle $\Delta\theta$) and Δ_x (the error of the deflection displacement Δx) will all decrease.

Increasing FOV size F will make the muon trajectory become longer, accompanied by the larger accumulative error and the worse reconstruction result.

Clearly, the spatial resolution Δ_x required from the MRPC detector is dependent on the detector separation d and the FOV size F. For example, a scattering angle of 17 mrad would result in values for Δ_x of 85 microns, 0.85 mm and 8.5 mm at 1, 10 and 100 cm separation distances respectively.



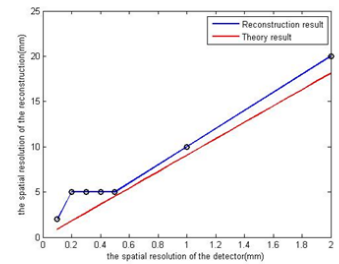
$$res_x \propto \Delta_x$$

$$res_x \propto F$$

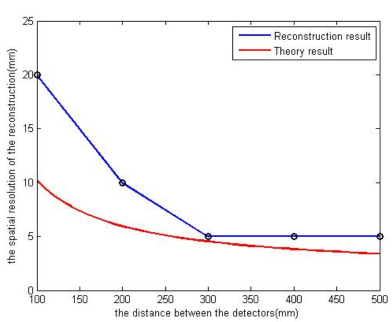
$$res_x \propto 1/d$$

The influence of the spatial resolution of MRPC to the spatial resolution of the reconstruction result

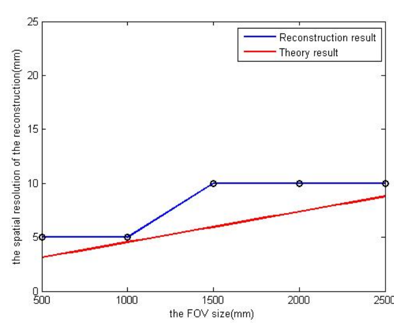
Line pair (mm)	CNR vs. different detector spatial resolution (mm)							
	0.1	0.2	0.3	0.4	0.5	1	2	4
20	3.443	3.504	3.681	3.595	3.375	3.008	2.213	1.019
10	3.403	3.336	3.430	3.083	2.928	2.530	1.482	0.525
5	3.230	2.679	2.618	2.246	2.263	1.707	0.728	0.147
2	1.904	1.315	1.168	0.822	0.804	0.452	0.093	0.095



The influence of the distance between MRPC detectors to the spatial resolution of the reconstruction result



The influence of the FOV size to the spatial resolution of the reconstruction result



Conclusion

Preliminary analysis based on theoretical research and simulation experiment shows the influence to the reconstruction spatial resolution from 3 factors: the MRPC detector spatial resolution, the detector separation distance and the FOV size. This work may help to predict the limit spatial resolution and guide the system designing.

Without considering the stochastic nature of moun tomography, the experiment result has some deviation compared to the theory result in ideal condition .

Experiments on TUMUTY system should be continuously conducted and the influence to the material distinguishing ability from the MRPC system will be studied in the future.

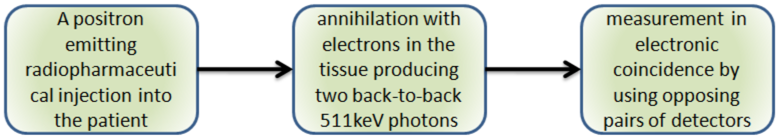
ROY, Arindam (VECC)

Performance simulation of a MRPC-based PET Imaging System

What is PET imaging ?

A powerful and sensitive technique for functional imaging in the field of Nuclear Medicine, based on the detection of a beam of radiation transmitted through the patient.

Basic Principle :



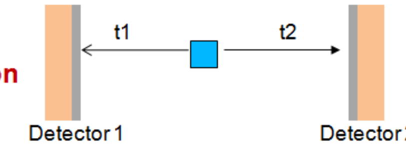
In TOF-PET, by measuring the time difference between the two detected photons we can get the annihilation position along the line of response

The width of the coincidence time difference = Δt (FWHM)

Width of the position of the annihilation ΔL (FWHM) = c $\Delta t/2$ = c$(2.355\sigma)/2$ ~ $\sigma/2$

Simulation Procedure:

Steps of simulation:



Step 1. GEANT4 to study the conversion of photons inside the detector material

Step 2. Standalone Monte Carlo code to study the MRPC response via the following procedures :

- Primary Ionisation
- Avalanche development
- Current calculation
- Charge calculation
- Time measurement of each detector
- Correlated time measurement for a pair of detectors

Correlated time resolution Δt = t1 ~ t2

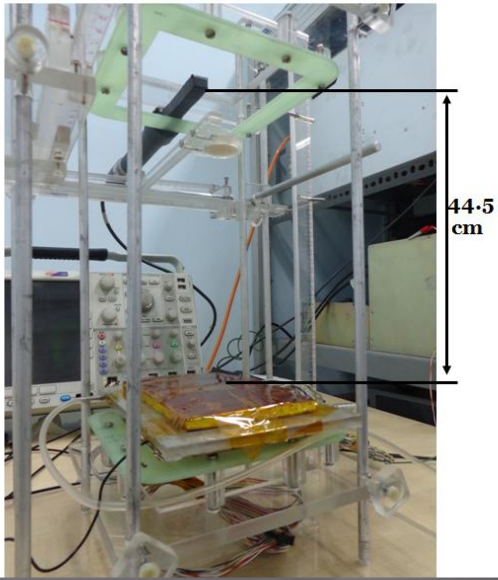
Distance between Scintillator and the MRPC: 44.5 cm

Length is measured from the MRPC (As shown in the x axis of the plot in next slide)

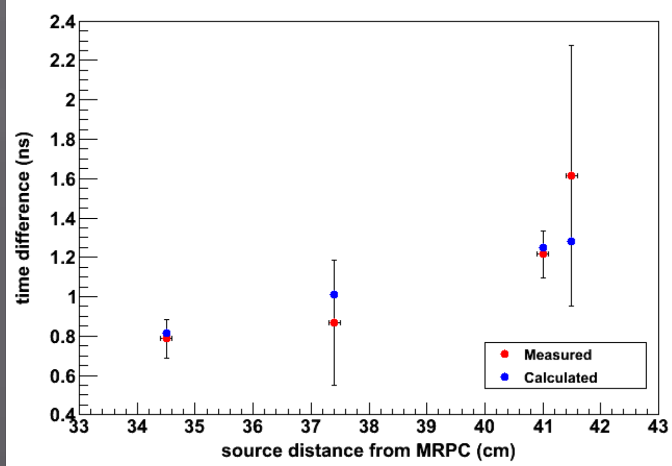
Calculated time difference = Stop time - Start time = (length/30)-((44.5-length)/30)

Velocity of gamma is (velocity of light) = 30 cm/ns

Electronic delay between start and stop signal (during experiment): 120.3 ns



Variation of time resolution with the distance between source and the detector



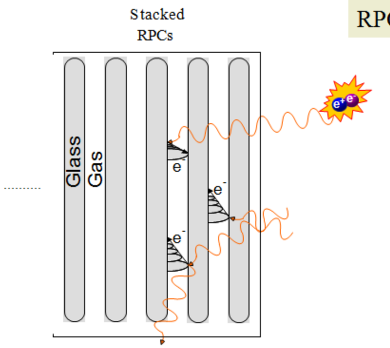
- Electronics delay has been subtracted while plotting the variation
- Error bars in the y axis is the statistical error
- From the plot, it can be said that a position resolution of 0.5 cm can be estimated with the current experimental set-up.

FONTE, Paulo (LIP)

Towards Very High Resolution RPC-PET for Small Animals

The basic idea for RPC-based TOF-PET

The converter-plate principle



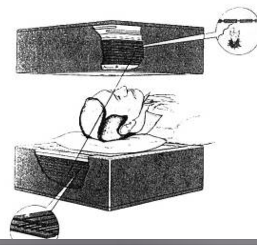
Use the electrode plates as a γ converter, taking advantage of the natural layered construction of the RPCs.

[Blanco 2002]

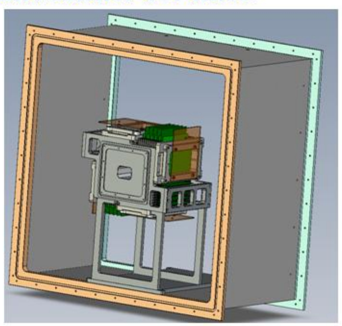
Time resolution for 511 keV photons:
(our routine lab-test tool)
90 ps σ for 1 photon
300 ps FWHM for the photon pair

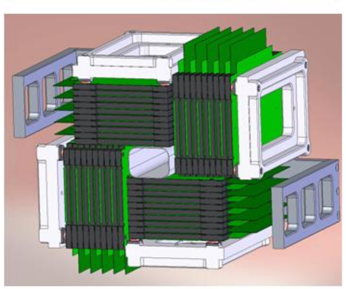
A previous work on PET with gaseous detectors (21 lead plates + 20 MWPCs = 7% efficiency)

"The Rutherford Appleton Laboratory's Mark I Multiwire Proportional Counter Positron Camera"
J.E. Bateman et al. NIM 225 (1984) 209-231

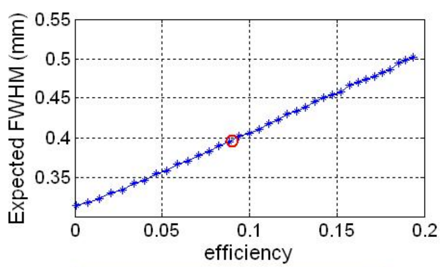


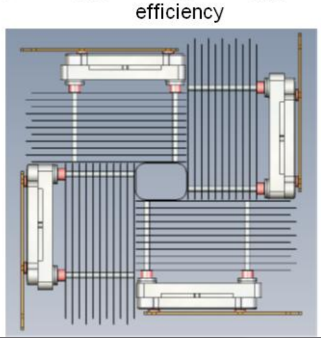
Full scanner for mice





Expected quantum efficiency and resolution



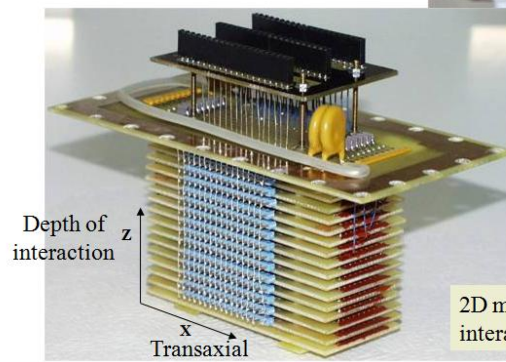


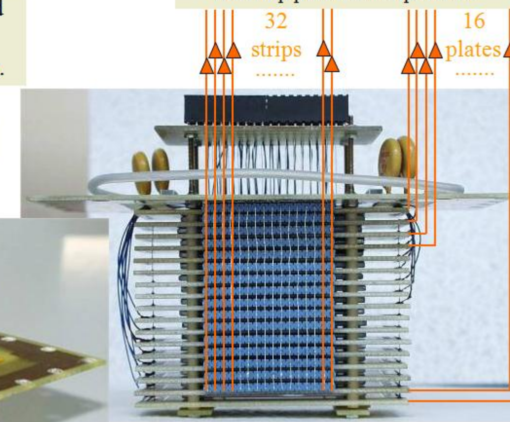
Small animal PET - a first prototype

Aimed at **verifying** the concept and show the **viability** of a **sub-millimetric spatial resolution**.

Charge-sensitive electronics allowing interstrip position interpolation

16 stacked RPCs





2D measurement of the photon interaction point

Conclusion

- An excellent space resolution of 0.4 mm FWHM was demonstrated in very realistic conditions without software enhancements (commercial tomographs > 1mm)
- A full scanner for mice is in an advanced completion stage, yielding a preliminary resolution of 0.52 mm FWHM
- It seems that the absolute efficiency may approach the simulated one.
- A competitive sensitivity (peakNEC) of 318Kcps has been suggested by simulations

- A very competitive PET scanner for small animals based on RPCs may be at hand, featuring excellent resolution (very much in demand today), reasonable efficiency and low cost.

Plan of the talk

- Introduction
- Detector R&D
- Signal Readout
- Detector performance
- New deployments
- Applications
- Outlook

New initiative

- Possibility of originating a CERN "RD*xx*" worldwide collaboration to enhance the development of RPC related technologies and strengthen the scientific exchange among various institutions.
  - No constraints of any type to the research freedom of each group.
  - Collaboration open to all partners who will decide to join it. The participation of as many groups as possible will be welcome, the only requirement being a genuine interest for our activity.
  - Sharing of all working items according to the expressions of interest of each group.
  - Sharing of the work results: organization, preparation of test beam facilities, solutions found for relevant problems.
  - To consider, in future the possibility to get from our funding agencies a minimal support for common activities such as gas for beam tests, electronic pool.
  - To consolidate a strongly interconnected and possibly numerous community to gain more international weight and to face the collaborations/competitions of the next future.

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